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DOCUMENT SECTION

# MINUTES AND PROCEEDINGS

of the Twenty-seventh meeting of the

ARMED FORCES - NRC VISION COMMITTEE

U.S.

November 10-11, 1950

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Acty Phys. Sec. Off., NIH

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Dept. of Psychology
The Ohio State University

Dr. Hoyt L. Sherman
Dept. of Fine Arts
The Ohio State University

Mr. Edgar L. Shriver
University of Rochester

Dr. Ernst Wolf
Wellesley College

Mr. Joseph Wulfeck
Dept. of Psychology
University of Rochester

VISION COMMITTEE SECRETARIAT

Dr. H. Richard Blackwell
Dr. W. M. Kincaid
Mr. John H. Taylor
Mrs. Kenneth A. Stone

Friday, November 10, Derby Hall — Page No.

1. The meeting was called to order by the Chairman. He introduced Dr. N. Paul Hudson, Dean of the Graduate School, Ohio State University, who extended greetings to the members of the Vision Committee and guests.

2. The Chairman called for corrections and additions to the Minutes of the 26th meeting. There were no corrections or additions.

3. Dr. H. Richard Blackwell, of the Vision Committee Secretariat, reported progress on the Armed Forces Visual Acuity Tests for clinical use. A summary of this report is contained in the Proceedings.................................................. 17

4. Dr. Benjamin J. Wolpaw presented a report of a working group which undertook to advise the Navy Department concerning visual standards for commissioned officers. The report is contained in the Proceedings.................................................. 19

5. Colonel Victor A. Byrnes presented a report on the proposed Armed Forces Visual Tester, a summary of which may be found in the Proceedings.................................................. 25

6. Lt. Comdr. Dean Farnsworth presented a report on the proposed Armed Forces Color Vision Test for screening. A copy of the report is contained in the Proceedings.................................................. 35

7. Dr. Stanley S. Ballard presented a discussion of experimental conditions for investigations on visual sensitivity and discrimination proposed by the International Commission of optics, a summary of which may be found in the Proceedings........... 43

8. Dr. Walter F. Grether presented a movie entitled "Flight Recordings of Pilot Eye Movements," A brief discussion of the movie may be found in the Proceedings.................................................. 49

9. Dr. H. Richard Blackwell presented a discussion of factors influencing visibility at high altitude, a summary of which may be found in the Proceedings.................................................. 51

10. Dr. S. Q. Duntley presented a paper entitled "The Visibility of Submerged Objects: I. Physical Factors," the text of which is contained in the Proceedings.................................................. 57

11. Dr. Harold S. Stewart presented a paper entitled "The Visibility of Aircraft Carriers."

12. Dr. Stanley S. Ballard requested permission of the Chairman to make an announcement concerning the awarding of the Adolph Lomb Medal of the Optical Society to Dr. H. Richard Blackwell. An abstract of Dr. Ballard's remarks is contained in the Proceedings .................................................. 62

Page No.

13. Dr. W. J. Crozier presented a paper entitled "Respired Oxygen and Visual Photosensitization," an abstract of which is contained in the Proceedings........................ 63

14. Dr. Lorrin A. Riggs presented a paper entitled "Binocular Measurements of Physiological Nystagmus," a copy of which is contained in the Proceedings................................ 65

15. Dr. Glenn A. Fry presented a report of research on accommodation and convergence at Ohio State University, a summary of which appears in the Proceedings.................... 69

Saturday, November 11

16. Dr. Theodore Dunham, Jr., presented a report of the working group on reflection optics, a copy of which appears in the Proceedings............................................. 75

17. Dr. Stanley S. Ballard reported on the preparation of the Bibliography on Reflection Optics. A summary of his remarks is contained in the Proceedings................................ 81

18. Dr. Richard Tousey presented a paper entitled "Measurements of the influence of Central Stops Upon Visual Resolution," a copy of which appears in the Proceedings..................... 83

19. Dr. H. Richard Blackwell presented a paper entitled "Measurements of the Influence of Central Stops Upon Visual Resolution," a copy of which appears in the Proceedings................................................ 87

20. Lt. Col. Alan E. Gee described and demonstrated a high-power Gregorian telescope of reflection optics design. A summary of his remarks appears in the Proceedings............ 95

21. Discussion of the reports on reflection optics................. 97

22. Col. Victor A. Byrnes presented a report on the meeting of the Executive Council which was held November 9. A summary of his remarks may be found in the Proceedings................. 98

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ABSTRACTS.................................................................. 100

The Armed Forces Visual Acuity Tests
for Clinical Use:
A Progress Report

H. Richard Blackwell
Vision Committee Secretariat

At the 26th meeting of the Vision Committee in Ottawa, visual acuity test charts intended for clinical use were exhibited and the Committee approved the transmittal of these charts to the military departments for their adoption as standard Armed Forces tests. The Secretariat forwarded the single form of the test, which was exhibited in Ottawa, to each of the three Surgeons General with the recommendation that the tests be adopted for overall service use. The question of adoption of the charts falls within the responsibility of the Armed Services Medical Materiel and Specifications Committee, of which the Chairman is Lt. Col. Alfred P. Thom. In August, 1950, the Vision Committee Secretariat received a letter from Lt. Col. Thom expressing the appreciation of his Committee to the Vision Committee for the development work which went into the visual acuity tests for clinical use. Colonel Thom called attention to the recommendation made by the Vision Committee in transmitting these tests that alternate forms of the tests be employed in order to discourage malingering. Colonel Thom requested that the Secretariat prepare the two alternate forms of the test in detail so that there would be no confusion concerning specification of the final charts to be procured by the military departments. Accordingly, the Secretariat undertook the task of drafting alternate forms of the near and far acuity test charts. In producing the alternate forms, the precise spacing of letters and general rules of construction which had been approved by the Vision Committee were employed. The only changes made in the charts were changes in the order of the letters employed.

Since the original form of the charts which had been approved by the Committee had been constructed merely to indicate the arrangement of letters, no serious attempt had been made in its construction to select letters so as to avoid duplications in adjacent letters in various directions. Since Colonel Thom desired sample tests in the precise form in which the final production would be manufactured, it was decided to withdraw the original single form of the acuity charts and to replace it with the third newly constructed alternate forms.

The three forms of the far acuity charts are presented below as figures 1-6, representing front and back of the three forms respectively. The letter sides of the small acuity charts are presented as figures 7, 8 and 9. Figure 10 presents the reading material which occupies the back side of each of the three near acuity tests.

The visual test charts for clinical use have been accompanied by the following recommendation proposed by the Subcommittee on Visual Standards and approved by the Vision Committee on November 14, 1949:

> In view of the fact that small differences in visual acuity of the same individual will undoubtedly appear when he is tested on the presently used Snellen chart and on the new chart, it is strongly urged that the three military departments issue a directive coincident with the distribution of the new chart specifying that it alone be used.

# ARMED FORCES FAR VISUAL ACUITY TEST

10'

1 N S

20/200 20%

5'

2 R Z O K

20/100 48.9%

3.5'

3 S C N Z O

20/70 64%

3.5'

4 K R V H D

64%

2.5'

5 N Z S O V

20/50 76.5%

2.5'

6 C D K R H

20/50 76.5%

FIGURE 1

# ARMED FORCES FAR VISUAL ACUITY TEST

10'

1 C Z

20/200 20%

5'

2 Z N K O

20/100 48.9%

3.5'

3 K Z V C H

20/70 64%

3.5'

4 O D S R N

64%

2.5'

5 D H R V O

20/50 76.5%

2.5'

6 S C Z N K

20/50 76.5%

FIGURE 2

# ARMED FORCES FAR VISUAL ACUITY TEST

| | | | | |
|---|---|---|---|---|
| 1 | K D | 20/200 | 10' | 20% |
| 2 | N R O C | 20/100 | 5' | 48.9% |
| 3 | D Z C S O | 20/70 | 3.5' | 64% |
| 4 | K H R V N | | 3.5' | 64% |
| 5 | S N H R K | 20/50 | 2.5' | 76.5% |
| 6 | Z O D C V | 20/50 | 2.5' | 76.5% |

FIGURE 3

| | | | | |
|---|---|---|---|---|
| 1 | Z V D S O | 20/50 | 2.5' | 76.5% |
| 2 | R H C K N | 20/50 | 2.5' | 76.5% |
| 3 | H S K Z C N O R | 20/40 | 2' | 83.6% |
| 4 | D N C O H R Z K V S | 20/30 | 1.5' | 91.5% |
| 5 | K O Z C R V H D S N | 20/25 | | 95.7% |
| 6 | S N V Z D O R K C H | 20/20 | 1' | 100% |
| 7 | R D N C Z V O S H K | 20/20 | 1' | 100% |
| 8 | O C Z R H N V D K S | 20/20 | 1' | 100% |
| 9 | D S H N O K C V Z R | 20/20 | 1' | 100% |
| 0 | H K R O Z D V N S C | 20/15 | .75' | 104.6% |
| A | Z N C K O R D S H V | 20/10 | .5' | 109.3% |

TO SCORE VISUAL ACUITY

All test scores are to be recorded in round numbers, that is, 20/20, 20/40, not 20/20+2, or 20/40−3.
For a score of 20/200, or ten minutes (10'), both letters must be read correctly.
For a score of 20/100, or five minutes (5'), three (3) out of four (4) letters must be read correctly.
For a score of 20/40, or two minutes (2'), six (6) out of eight (8) letters must be read correctly.
For all other scores, seven (7) out of ten (10) letters must be read correctly.

FIGURE 4

| | | | | |
|---|---|---|---|---|
| 1 | H Z D C V | 20/50 | 2.5 | 76.5% |
| 2 | N S O R K | 20/50 | 2.5' | 76.5% |
| 3 | O K R C Z S H N | 20/40 | 2' | 83.6% |
| 4 | N H Z O V D K R C S | 20/30 | 1.5' | 91.5% |
| 5 | Z N C K O R D S H V | 20/25 | 1.25' | 95.7% |
| 6 | S R N D Z V H O K C | 20/20 | 1' | 100% |
| 7 | N Z H R C K S V O D | 20/20 | 1' | 100% |
| 8 | O C R D S Z V N H K | 20/20 | 1' | 100% |
| 9 | D K N C R H Z S V O | 20/20 | 1' | 100% |
| 0 | C V R S K O D N Z H | 20/15 | .75' | 104.6% |
| A | H S O K N D Z C R V | 20/10 | .5' | 109.3% |

TO SCORE VISUAL ACUITY

All test scores are to be recorded in round numbers, that is, 20/20, 20/40, not 20/20+2, or 20/40−3.
For a score of 20/200, or ten minutes (10'), both letters must be read correctly.
For a score of 20/100, or five minutes (5'), three (3) out of four (4) letters must be read correctly.
For a score of 20/40, or two minutes (2'), six (6) out of eight (8) letters must be read correctly.
For all other scores, seven (7) out of ten (10) letters must be read correctly.

FIGURE 5

| | | | | |
|---|---|---|---|---|
| 1 | C S V Z N | 20/50 | 2.5' | 76.5% |
| 2 | R H D O K | 20/50 | 2.5' | 76.5% |
| 3 | S C K H Z N R O | 20/40 | 2' | 83.6% |
| 4 | V K S D Z H O C N R | 20/30 | 1.5' | 91.5% |
| 5 | R H D Z O V C N S K | 20/25 | 1.25' | 95.7% |
| 6 | C K S O V D H Z R N | 20/20 | 1' | 100% |
| 7 | O S V N K H Z D C R | 20/20 | 1' | 100% |
| 8 | H Z N S R O C K V D | 20/20 | 1' | 100% |
| 9 | D R Z C S K O H N V | 20/20 | 1' | 100% |
| 0 | H O K R V C S D Z N | 20/15 | .75' | 104.6% |
| A | Z S H N D V R C K O | 20/10 | .5' | 109.3% |

TO SCORE VISUAL ACUITY

All test scores are to be recorded in round numbers, that is, 20/20, 20/40, not 20/20 + 2, or 20/40 − 3.
For a score of 20/200, or ten minutes (10'), both letters must be read correctly.
For a score of 20/100, or five minutes (5'), three (3) out of four (4) letters must be read correctly.
For a score of 20/40, or two minutes (2'), six (6) out of eight (8) letters must be read correctly.
For all other scores, seven (7) out of ten (10) letters must be read correctly.

FIGURE 6


FIGURE 7


FIGURE 8

## ARMED FORCES NEAR VISUAL ACUITY TEST


FIGURE 9

**14**

I walked up the street, gazing about, until near the market house I met a boy with bread. I had made many a meal on bread, and asked him where he got it. I then went to the baker's and asked for biscuit such as we had in Boston. I asked for a three penny loaf and was told that they had none such. Not knowing the difference of money and the greater cheapness, I bade him give me three penny worth of any sort. He gave me three great puffy rolls. I was surprised at the quantity but took it, and walked off with a roll under each arm.

**21**

Thus I went up Market Street as far as Fourth Street, passing by the house of Mr. Read, my future wife's father. She, standing at the door, saw me and thought I made a most awkward appearance, as I certainly did. Then I turned and went down Chestnut Street and a part of Walnut Street, and found myself again at the wharf. Being filled with one of my rolls, I gave the other two to a woman and her child.

**28**

By this time the street had many clean and well dressed people in it, all walking the same way. I joined them and was led into the great meeting house of the Quakers. I sat down among them and after looking around a while and hearing nothing said, I fell fast asleep. This was the first house I was in, or slept in, in Philadelphia.

**35**

Looking in the faces of people, I met a young man whose countenance I liked, and asked if he would tell me where a stranger could get lodging. "Here", said he, "is one place that entertains strangers, but it is not a reputable house. If thee wilt walk with me, I will show thee a better." He brought me then to a place in Water Street, where I engaged a room and got dinner.

**49**

While I was eating it several sly questions were asked me, as it seemed to be suspected from my youth and appearance that I might be some run-away. After dinner, my sleepiness returned, and being shown to a bed, I lay down without undressing and slept soundly till six in the evening.

**70**

Our city, though laid out with beautiful regularity, the streets crossing each other at right angles, had the disgrace of allowing those streets to remain long unpaved. The wheels of heavy carriages plowed them into a quagmire.

FIGURE 10

Recommendations for Revision of the Visual Requirements
for Midshipment and newly commissioned officers of the U. S. Navy

Prepared by a working group
of the
Armed Forces-NRC Vision Committee

Benjamin J. Wolpaw, Chairman

(Editorial note: The following report represents the final report prepared by the working group. It contains minor changes in wording which were suggested by the discussion at the Vision Committee meeting. The discussion of the report as it was given at Columbus may be found at the conclusion of this, the revised report.)

A working committee of the Armed Forces-NRC Vision Committee met on October 1, 1950, at the U. S. Naval Academy, Annapolis, Maryland.

This meeting was called at the request of the Navy Department to consider a revision of the visual requirements for Midshipment and newly commissioned officers of the U. S. Navy.

Present at the meeting were:

1. Captain J. W. Allen, (MC) USN, Senior M. O., U. S. Naval Academy
2. Captain Robert A. Bell (MC) USN, Bureau of Medicine & Surgery
3. Captain Wilbur E. Kellum (MC) USN, Naval Medical Research Institute
4. Captain C. G. McCormack (MC) USN, Bureau of Medicine and Surgery
5. Captain F. B. C. Martin, USN, Director Procurement BuPers.
6. Captain J. R. Reid, Jr., (MC) USN, Medical Officer, Bancroft Hall
7. Captain John T. Smith (MC) USN, Bureau of Medicine & Surgery
8. Captain C. W. Shilling (MC) USN, Office of Naval Research
9. Cdr. G. W. Hurst, (MC) USN, Bureau of Medicine & Surgery
10. Cdr. Edward A. Hynes, (MC) USN, U. S. Naval Academy
11. Everett G. Brundage, Ph.D., Research Division BuPers.
12. Henry A. Imus, Ph.D., Office of Naval Research
13. Hedwig S. Kuhn, M. D., Hammond, Indiana
14. John L. Matthews, M. D., San Antonio, Texas
15. W. M. Rowland, M. D., Wilmer Institute, Baltimore, Maryland
16. Richard G. Scobee, M. D., St. Louis, Missouri
17. Louise L. Sloan, Ph.D., Wilmer Institute, Baltimore, Maryland
18. John H. Sulzman, M. D., Troy, New York
19. Benjamin J. Wolpaw, M. D., Cleveland, Ohio

Cdr. Hynes, Ophthalmologist at Annapolis, presented an excellent survey of the present situation at the Naval Academy. In the three upper classes 402 men out of a total of 2527, or 15%, could not meet the visual requirements for a commission at graduation. In the Fourth Year Class, to be graduated in June of 1951, 17% of the class could not meet visual standards for a commission in the Line. This is a high rate of attrition. Not only has this government spent a great sum of money to educate these men for four years, only to find they cannot be Line Officers, but the Navy has 17% fewer Officers in June than it had anticipated.

This problem is not limited to the Naval Academy at Annapolis, but is common to all colleges having NROTC programs. The same physical requirements exist for all officer candidates whether at the Academy or outside colleges.

In order to salvage more men from the various graduating classes, the problem resolved itself into two possibilities:

1. Shall the visual requirements be made more stringent for admission to the Academy and NROTC program?

2. Shall the visual requirements for a commission in the Line be revised so as to admit more of the men rejected under present rules?

Consideration was first given toward more stringent admission requirements. Based upon statistics gathered at the Naval Academy during the past four years it is possible to predict the attrition rate at graduation from the cycloplegic refractive error on admission.

In the class of 1945 there were 44 men 17 or 18 years of age showing from -.25 to +.25 on admission. Of these, 93% required a myopic correction at graduation. There were 67 nineteen year olds with the same refractive error on entrance and of these 73% became myopic. Among the 20 year old matriculants 55% failed visual requirements over four years. In the 20-21 year group only 17% failed visual requirements. It is evident that the older the candidate with 20/20 vision and a low initial refractive error the more likely he is to qualify for commission.

Of 2057 men in the 1949-1950 classes, of those who initially showed +.50 to +1.00 hyperopia only 11 developed any myopia during the four years, and of these only six failed visual requirements. Hence, if the admission standard required at least 0.50 diopter hyperopia under cycloplegia the loss at time of graduation would be drastically reduced. This situation would be ideal if sufficient candidates to fill the Academy and NROTC program could be obtained, who also meet the scholastic standards.

It is recognized that the requiring of a cycloplegic examination is an added hazard for the Academy applicant not faced by the NROTC program applicant. The former will be examined by a Navy doctor whereas under the Holloway plan the NROTC student will probably be examined by any doctor of his own choice.

Realizing the high mortality rate of those men with 20/20 vision and a myopic error at the time of admission to the program, it was felt that if a requirement of one-half diopter of hyperopia could not be established then a limit must be placed upon the degree of myopia under cycloplegia which a candiate could have. This would eliminate those men with a 90% chance of failure.

A revision of the present standards required at time of graduation was deemed essential because:

1. It may not be possible to fill the midshipmen ranks with acceptable students if the entrance requirements are made too stringent.

2. In these critical years it is essential to salvage as many trained men as possible who would be rejected under present standards.

Considering the increased use of newer devices such as radar and the widespread use of binoculars it was felt that Line Officers probably no longer need 20/26 unaided vision, the requirement for which there never has been any scientific basis.

The industrial survey conducted over a period of 10 years by a combined group of Physicians and Psychologists at Purdue University revealed 20/40 uncorrected vision to be the critical point in job success. This survey included men in a

wide variety of tasks such as machine operators, motor vehicle operators, guards, common laborers, supervisory staff, and many others. There are probably few tasks carried out by a Line Officer which would not fall into a category examined in labor.

Dr. Scobee reported on approximately 600 myopic individuals whose vision was plotted against refractive error in scattergrams. These charts indicated that the majority of myopes with 20/40 vision or better would not have more than the spherical equivalent of one diopter of myopia.

An attempt was made at the Academy to relate the loss of visual acuity to overall proficiency of the midshipmen. No correlation was found. The class standing attained by the student was not influenced by his visual acuity.

In the Class of 1951 there are 129 men not qualified for commission because of defective vision. Of this group 80 or 62% would qualify under the proposed rules. This is a very appreciable saving in officer material.

There has been some difficulty in the women's services due to varying standards of visual acuity in the WAVES, Women Marines, and Nurses. From an administrative standpoint it would be advisable for all women's services to have similar standards. This problem was discussed and a recommendation on it will follow.

The working committee appreciates the fact that a comprehensive job analysis of visual capacity versus visual demands in the Navy would be advisable. Such a study, properly carried out, would take a considerable length of time. During this study the Navy, if it maintained present standards, would lose 15 to 17 percent of the graduates of the Naval Academy and NROTC schools. In the next two or three critical years the service can ill afford to lose these men. Should a careful job analysis show the suggested standards to be in error then a further revision can be made.

The adjusted standards should have little effect on the retirement status of officers.

The men to be commissioned will all be over 21 years of age. Their most difficult years of close work will have been finished. Myopia increases but little beyond this age period and with the advent of presbyopia their distant visual acuity may improve. For those officers doing considerable close work the small myopic error will be no handicap.

The Committee desires to emphasize the fact that the eye standards heretofore set by the Navy are not being "lowered" but instead are being "adjusted" in the light of modern knowledge. Until the advent of the Purdue Industrial Study there was no scientific evidence justifying any cutoff point.

Based upon the evidence now available the following recommendations are proposed:

1. For entering Midshipment and NROTC students:

   Visual acuity of 20/20 in each eye and no more than one-half diopter of myopia in any meridian under cycloplegia.

2. For commission as a Line Officer in the U. S. Navy:

   Visual acuity not less than 20/40 in each eye, correctible to 20/20 and with no refractive error of more than the spherical equivalent

of minus one under cycloplegia.

3. The visual requirements for all women's services to be standardized in accord with the present requirements for WAVES.

4. It is recommended that a formal study to determine the visual acuity requirements for Naval Officers be carried out by the Office of Naval Research.

DISCUSSION:

Captain Smith asked Dr. Wolpaw whether or not the working group was going to recommend that candidates be refracted before admission to Annapolis. Captain Smith noted that this recommendation, which had been discussed at the Annapolis meeting, seemed to have been deleted from the report of the working group. Captain Smith expressed his view that commissioning officers with 20/40 vision might be acceptable, but it was certainly not as desirable as commissioning only those men with 20/20 vision. If the candidates were sufficiently well screened prior to admission to Annapolis, it would be possible to reduce the number of graduates of Annapolis with 20/40 vision. Captain Smith expressed the opinion that the recommendation that a refraction be required of all candidates admitted to Annapolis should be included in the report of the working group.

Dr. Wolpaw commented that the question of whether or not to require a refraction of candidates entering Annapolis had received consideration by the working group. Dr. Wolpaw expressed the belief that the number of men who would be disqualified on the basis of a refraction prior to admission to Annapolis would be small. He expressed some concern with the administrative difficulties of failing to admit to Annapolis those candiates who had adequate visual acuity but who, on the basis of myopia under cycloplegia, would be expected to develop reduced visual acuity during the period of study at Annapolis.

In addition, Dr. Wolpaw noted that, under the Holloway plan, candidates for Annapolis are given their medical examinations all over the country. Dr. Wolpaw expressed some doubt as to feasibility of accepting refractive examinations made by a large number of ophthalmologists.

For these reasons, Dr. Wolpaw expressed his belief that the requirement of a refractive examination prior to admission to Annapolis should not be made.

Dr. Scobee commented on another aspect of the question. He noted that the Navy commissions a large number of candidates from the NROTC programs. Presumably, these men could not be required to have a refraction prior to admission to the NROTC program. Dr. Scobee asked whether the question of refractive examination would not apply equally well to the NROTC candidates as to the Annapolis candidates.

Dr. Sloan commented that in her opinion the requirement of a refractive examination prior to admission to Annapolis would be desirable. She recommended that the report of the working group should clearly state this recommendation, and that they Navy Department should decide whether or not such a recommendation created undue administrative difficulties.

Captain McCombs expressed his concurrence with this view, and recommended also that the working group report the amount of reduction in attrition due to reduced visual acuity which would be expected if refractive examination were required prior to admission to Annapolis.

Captain Shilling expressed his concurrence with the view that the working group should report what it regarded as the optimum procedure for selection of candidates to Annapolis, and let the Navy Department worry about administrative aspects of the problem.

Dr. Kuhn emphasized again the second point which Dr. Wolpaw made; namely, the difficulty of getting adequate refractive examinations from all over the country.

It was the consensus of opinion that the working group should recommend requiring a refractive examination for admission into either Annapolis or the NROTC program. This recommendation is included in the final report of the working group presented above.

Mr. Fisher asked what the reduction in rejection of graduates of Annapolis would be with the new standard of 20/40 vision adopted for commission.

Dr. Wolpaw replied that reduction of the visual requirements for commissioning to 20/40 would be expected to reduce the rejection percentage from 17% to 7%.

Mr. Brown asked whether the working group was recommending any change in the visual requirements for special duty.

Dr. Wolpaw replied that no such recommendation would be made by the working group.

Captain McCombs expressed concern about one aspect of the new commissioning requirements. He noted that men who are commissioned with visual acuity of 20/40 are able to go into the Supply Corps only. He stated that personnel in the Supply Corps feel that the Supply Corps is becoming completely staffed by "visual rejects." Captain McCombs asked if there were any evidence that personnel with 20/40 would be able to do as well in administrative work as those with better visual acuity.

Dr. Wolpaw replied that results of tests of industrial situations clearly indicated that 20/40 vision corrected to 20/20 does not in any way impair performance in administrative jobs.

# Report on the Proposed Armed Forces Vision Tester

Colonel Victor A Byrnes
Chairman of the working group on the visual screening examination

The Vision Committee has had a continuing interest in the development of a machine-type visual screening examination. On August 26, 1947, the Subcommittee on Visual Standards and Testing directed an unsolicited recommendation to the Surgeons General of the Army and Navy and to the Air Surgeon recommending that consideration be given to this type of visual examination. Partially as a consequence of this recommendation, a contract was made between Dr. Louise Sloan and the Office of Naval Research to provide for the study of machine-type visual screening examinations for possible application for testing in the Armed Forces.

On 24 March 1948, a request was received from the Deputy Air Surgeon that the Vision Committee consider what recommendations, if any, could be made at that time concerning the approximate characteristics and use of a visual screening examination. The Subcommittee on Visual Standards held a series of meetings and adopted a recommendation which was approved by the Vision Committee at the 23rd meeting on March 5, 1949. This recommendation stated that, on the basis of then available information, the Ortho-Rater manufactured by Bausch and Lomb Optical Company was regarded as the most satisfactory commercially available machine test. Modifications were proposed which were intended to make of the Ortho-Rater a suitable test for use by the Air Surgeon. It was carefully stated that further research by Dr. Sloan under the Office of Naval Research contract might be expected to modify somewhat the recommendations made.

On July 12, 1950, the international situation prompted the Air Force to request that the Vision Committee re-examine the recommendations made on March 5, 1949, in order to produce the most adequate possible recommendations for development of a mass screening examination to be put into immediate use in the Air Force. Conversations with the military liaison representatives from the Army and the Navy indicated that these two Services were also much concerned with the need for a visual screening examination. It was decided to call a meeting immediately in order to attempt to provide the necessary recommendations. Accordingly, a meeting was called for July 19, 1950, in Washington at which representatives from the three military departments and Vision Committee were present. The attendance at the meeting was as follows:

Col. Victor A. Byrnes, USAF, School of Aviation Medicine, Randolph Field, Texas
Dr. Donald Baier, USA, Office of the Adjutant General, Washington
Capt. Oran Chenault, USN, School of Aviation Medicine, Pensacola, Florida
Lt. Comdr. Dean Farnsworth, USN, Medical Research Laboratory, New London, Connecticut
Dr. David Freeman, Washington University School of Medicine, St. Louis, Mo.
Dr. Henry A. Imus, USN, Office of Naval Research, Washington
Dr. Deane B. Judd, National Bureau of Standards, Washington
Col. Austin Lowrey, Jr., USA, Walter Reed General Hospital, Washington
Dr. John L. Matthews, San Antonio, Texas
Major Robert A Patterson, USAF, Office of the Air Surgeon, Washington
Lt. George W. Rand, USN, School of Aviation Medicine, Pensacola, Florida
Dr. Richard G. Scobee, Washington University School of Medicine, St. Louis, Mo.
Dr. L. Harold Sharp, USA, Office of the Adjutant General, Washington
Capt. C. W. Shilling, USN, Office of Naval Research, Washington
Dr. Louise Sloan, Johns Hopkins University School of Medicine, Baltimore, Maryland
Comdr. Harold Smedal, USN, Bureau of Medicine and Surgery, Washington
Capt. John T. Smith, USN, Bureau of Medicine and Surgery, Washington

Dr. Benjamin J. Wolpaw, Cleveland, Ohio
Dr. H. Richard Blackwell, Vision Committee Secretariat, University of Michigan, Ann Arbor, Michigan

It was generally agreed that development of a visual screening examination was imperative, particularly in the event of possible mass mobilization, for the following reasons: In the first place, use of a machine type screening examination would eliminate the necessity for constructing numerous twenty-foot eye lanes. The cost of constructing such eye lanes was found to be very great in the last war. The use of a single machine type test would maximize the uniformity of examination results obtained at different testing centers across the country. The use of a mass screening examination would save large amounts of time in the medical examination and would permit the use of technicians rather than professionally trained eye specialists.

The essential general characteristics of a mass screening examination were considered to be the following: First, there was a need for numerous visual tests. Secondly, provision must be made for easy replacement of tests in the screening examination in the event that changes in requirements become necessary.

It was the consensus of opinion of the July 19 conference that only one commercially available instrument is able to meet these specifications satisfacorily. This instrument is the Ortho-Rater produced by the Bausch & Lomb Optical Company. Other machine tests presently available either do not permit the use of a sufficient number of tests with ease of replaceability, or else mechnaical features prevent use of certain kinds of tests, for example, the polaroid system employed in the Sight Screener necessitates the use of test targets of low contrast. In addition, the single flat slide of the Sight Screener does not permit as many kinds of tests as does the drum arrangement in the Ortho-Rater. Members of the conference wished to emphasize that they would be very pleased to recommend additional machine tests as they become commercially available, provided, of course, they meet all specifications deemed necessary by the working group.

It was the consensus of opinion of the July 19 conference that the testing of color vision cannot feasibly be undertaken in a machine type vision tester. For this reason, an entirely separate test of color vision has been developed which will be described in detail by Lt. Comdr. Dean Farnsworth in the succeeding paper. The tests to be described here constitute the entire visual screening examination with the exception of the color vision test. The tests to be included in the standard tester may be described as follows:

1. VERTICAL PHORIA AT DISTANCE

Vertical phoria at distance is to be tested by means of a new slide constructed in accordance with the basic principle of the present Ortho-Rater test of vertical phoria. A sample of the test to be employed is presented in Figure 1. The test demonstrated in Figure 1 differs from the conventional Ortho-Rater test in that the range of phorias and the step between successive items are varied. In this test, a total range from two prism diopters of left hyperphoria to two prism diopters of right hyperphoria is covered in steps of 0.5 prism diopters. Variable prisms of four diopter power are to be mounted before each eye. These prisms are to employed as a safeguard against malingering. Since, in the phoria test, a particular number corresponds to orthophoria, it would be a very simple matter indeed for candidates to learn the correct answer and to give it when they are tested. For this reason, an adequate safeguard against malingering is necessary. The malingering prisms would be utilized in the following manner. The examinee would be required to indicate the "stair step" intersected by the dotted line for each of a series of settings

of the variable prism. One of the settings of the variable prism will be zero prism power. This setting alone will be recorded. It will also be possible to utilize the variable prism in order to provide a demonstration of the principle of the test. It is important for the examinee to realize that the lateral relationship between the "stair step" and the dotted line does not matter, but that only the vertical intersection of the dotted line on the "stair step" is of significance. This relation can be indicated by deliberately varying the lateral placement of the dotted line with respect to the "stair step," telling the examinee that this kind of variation is of no significance to the response to be made.

2. LATERAL PHORIA AT DISTANCE

Lateral phoria at distance is to be tested by means of a new slide constructed in accordance with the basic principle of the present Ortho-Rater test. A sample of the test to be employed is presented in Figure 2. The test demonstrated in Figure 2 differs from the conventional Ortho-Rater test in that the range of phorias tested and the step between the successive items is different. In the test to be employed in the visual examination, the range from ten prism diopters of esophoria to ten prism diopters of exophoria is to be employed, in steps of one prism diopter. As in the case of the vertical phoria test, the variable prisms are to be employed as a check on malingering. In this case, settings of the variable prisms change the number at which the arrow points. The examinee will be required to respond by giving the number at which the arrow points for each of a number of settings of the variable prisms, one of which is the setting at zero deviation which is to be employed as the test score.

3. MONOCULAR ACUITY AT DISTANCE

Monocular acuity at distance is to be tested by means of special letter slides which have been prepared in accordance with a proposal made by Dr. Louise Sloan. The basic principle is that the same ten letters are to be employed at each level of difficulty so that the known variation in difficulty of different letters will not lead to reversals in difficulty of lines of characters. It is possible to employ the full list of ten letters in all except the 20/400 line for which only three letters may be employed. The three letters to be employed have been selected on the basis of demonstrated average difficulty with the average of the ten letters.

Four new slides have been prepared for testing letter acuity at distance and are presented as Figures 3, 4, 5, and 6. Figures 3 and 5 are alternate slides to be employed in testing visual acuity between the limits 20/400 and 20/70. Note that the arrangement of letters is different for each side of each of the two slides. Thus, there are four combinations of letters which may be employed to test visual acuity in this range, two arrangements for the left eye and two arrangements for the right eye. Slides 4 and 6 represent the alternate forms of the test for acuity within the range 20/50 to 20/12. Note again that there are four combinations of letters, two for testing acuity in each eye. It is anticipated that the examiner will vary the test employed with successive examinees, so that the presence of alternate forms will serve to discourage malingering.

4. DEPTH PERCEPTION AT DISTANCE

Depth perception at distance is to be tested by means of a new slide designed by Dr. Louise Sloan. The form of the test may be judged by examining Figure 7 which represents a sample of the depth perception test. (The depth perception test is to be slightly different from the sample in Figure 7 in that the small circles and the letters F and L which are outside the large black squares are to be eliminated. The arrow is to be used as a test of fusion.) It is intended that the

examiner will request the examinee to describe exactly what he sees, checking the truthfulness of the answers by covering one eye of the examinee with an occluder. With binocular vision, the examinee should report seeing an arrow. With the left eye covered, the examinee should see only the head of the arrow, whereas with the right eye covered, the examinee should see only the tail of the arrow. If the examiner finds that the examinee gives the correct normal answers for binocular vision, and if tests made with the occluder over one eye indicate that the examinee was not malingering, the examiner indicates on the record blank that the examinee has passed the fusion test. Abnormal responses of the following kinds may occur when the examinee is allowed to use both eyes: the examinee may report seeing two arrows side by side which indicate thepresence of double vision. The examinee may see only the head or only the tail of the arrow which indicates suppression of the arrow in one eye in binocular vision. The depth test is given only to those examinees who pass the fusion test. (The depth test is also omitted if the examinee's visual acuity in either eye is as poor as 20/50.)

A demonstrator device is furnished as accessory equipment for the depth perception test. The demonstrator device consists of a piece of thick plastic which has painted on its front surface a series of circles, and on its back surface, a single circle. The examinee is told that the depth perception test in the visual tester will look to him just like the demonstration sample, in that one of the circles will appear to be farther away from him than the others. There will be an alternate form of the depth perception test which will be identical with Figure 7 except that the arrangement of the sequence of correct answers will be different. It is intended that the examiner may utilize the two depth perception tests for successive examinees in a random sequence in order to discourage malingering.

## 5. VERTICAL PHORIA AT NEAR

The test for vertical phoria at near is entirely similar to the test of vertical phoria at distance. A sample of the test is given in Figure 8. The range to be covered in this case is from two prism diopter of left hyperphoria to two prism diopter of right hyperphoria in steps of 0.5 prism diopters.

## 6. LATERAL PHORIA AT NEAR

The test for lateral phoria at near is entirely similar to the test for lateral phoria at distance. A sample of the test is presented as Figure 9. The range to be covered is from 12 prism diopters of esophoria to 20 prism diopters of exophoria in one prism diopter steps.

## 7. MONOCULAR VISUAL ACUITY AT NEAR

The tests of monocular visual acuity at near are entirely similar to the tests of monocular visual acuity at distance. There will be one slide to cover the range from 20/400 to 20/70. A sample of this slide is not presented, since it is not yet available. The second slide is to be utilized in testing the range from 20/50 to 20/12. A sample of this slide is presented as Figure 10.

## 8. PRISM DIVERGENCE AT NEAR

The working group considered the possibility of employing a test of prism divergence at near as an integral part of the vision tester. It is the final recommendation of the working group that this test not be recommended as a standard item for inclusion in the vision tester. However, the Air Force is sufficiently interested in exploring the use of the prism divergence test so

that the working group has proceeded to develop such a test with the understanding that the test will be optional for inclusion in those vision testers which are to be used in the Air Force. For the test of prism divergence, a rotary Risley prism totaling thirty prism diopters of power is to be mounted. The examinee will be required to fixate a test slide, a sample of which is presented as Figure 11. This fixation will occur with the rotary prism set for zero power. The examiner will then introduce prism power before the eyes of the examinee in order to determine the limit of prism power which can be overcome and fusion maintained. The setting of the Risley prism at which the examinee loses fusion is recorded as the score.

It was emphasized that the visual screening examination as described above is intended to be recommended for adoption in the Armed Services. The test is to be recommended in order that significant savings of time and money may be possible without any significant sacrifice in the adequacy of visual screening. The Vision Committee does not intend to recommend what cut-off the Services shall use either for general acceptance into military service or for acceptance into specialized training.

DISCUSSION:

Dr. Harlow stated the interest of the Army in having a test of binocular acuity included in the visual screening examination. He requested that this matter be given consideration by the working group.

Colonel Byrnes replied that the working group had considered at some length the question of a test of binocular acuity and had rejected it. He asked Dr. Harlow if he would care to get further evidence on the desirability of such a test.

Dr. Harlow asked Dr. Uhlaner to present the evidence on which the Army request for a binocular acuity test was based.

Dr. Uhlaner reported data obtained by the Adjutant General's Office on military populations. It was found that the correlations between monocular acuity and binocular acuity were low, in the neighborhood of 0.56 to 0.61. Correction for attenuation raises them slightly. The correlations between acuity with the best eye and binocular acuity, with correction for attenuation, falls in the range from 0.79 to 0.83. These figures are all for acuity at distance. Dr. Uhlaner reported that the correlations are considerably lower for acuity at near. Dr. Uhlaner expressed his conviction that these figures indicate that binocular acuity is sufficiently different from monocular acuity to suggest that it should be tested, particularly since one might expect a priori that binocular acuity rather than monocular acuity would show the highest correlation with job success.

Col. Byrnes replied that the length of the examination is fixed by the Ortho-Rater drum, and that it would not be possible to add any additional tests to the present examination. Colonel Byrnes expressed his conviction that it is imperative to test acuity in each eye and suggested that the addition of a binocular acuity test would not be expected to add enough to the knowledge gained from the test to warrant the extra test even if it could be arranged.

Lt. Comdr. Farnsworth reported that correlations between monocular acuity in the best eye and binocular acuity obtained with military populations at

New London were much higher than those reported by Dr. Uhlaner. Comdr. Farnsworth reported that the correlations obtained in New London were in the neighborhood of 0.90. He expressed his conviction that this question had been settled by the Subcommittee on Visual Standards some years ago.

Dr. Imus commented that the development of the visual tester was carried out with particular exphasis upon the ease of substituting test items or adding new tests. He suggested that it would be possible for the Army to employ a binocular acuity test if they wished to do so on a developmental basis. Dr. Imus also pointed out that the instrument developed by the working group was designed for mass screening and not for classification and assignment. Dr. Imus expressed his belief that for the purpose of mass screening, it is essential to test monocular acuity in each eye, whereas it might well be, for classification and assignment purposes, for binocular acuity to be tested.

Dr. Scobee commented that all the members of the working group were well aware that binocular acuity is different from monocular acuity. He reported that, except under special rare conditions, examinees will demonstrate better binocular acuity than monocular acuity. Dr. Scobee emphasized the necessity for knowing the monocular acuity in each eye for the purposes of screening. He stated again a belief that the New London studies had shown that the testing of binocular acuity adds very little to the knowledge you have about most examinees. The only examinees who are expected to have worse or equal binocular acuity and monocular acuity are those examinees with sufficiently large phorias. Such examinees will, of course, be picked up by the phoria testing in the vision tester.

Dr. Kuhn commented that the binocular acuity test was originally put into the Ortho-Rater for purposes of orientation of the examinee only.

Dr. Uhlaner emphasized that, in his view, the visual screening examination is intended to predict something about the adequacy of the examinee in military jobs. The screening examination is not a clinical test. Therefore, Dr. Uhlaner emphasized that it seemed to him imperative that tests be included in the screening examination which would have maximum validity in predicting job success.

Dr. Blackwell noted that construction of a test for binocular acuity is extremely simple and suggested that a binocular test be constructed as an optional portion of the visual screening examination, and that the Services wishing to use it substitute it for the alternate forms of the monocular acuity tests at distance.

Colonel Byrnes stated his agreement with this proposal and suggested that the instructions for the visual screening examination include reference to the optional test of binocular visual acuity.

Dr. Spragg asked whether the present visual acuity test is more difficult to administer than the checkerboard acuity test utilized in the original Ortho-Rater.

Dr. Sloan replied that she believed the letter acuity test was slightly more difficult to administer than the checkerboard test, but not greatly so. She stated that in her belief the examiners will soon learn the tricks of administering the letter acuity test, and that it will then be as rapid to administer as the checkerboard acuity test.


FIGURE 1

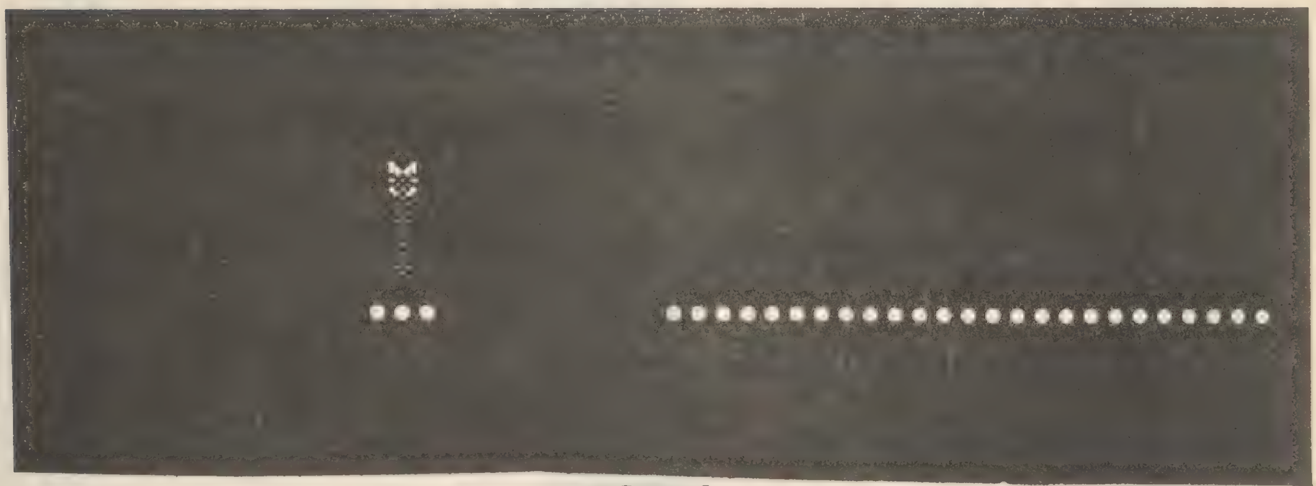


FIGURE 2

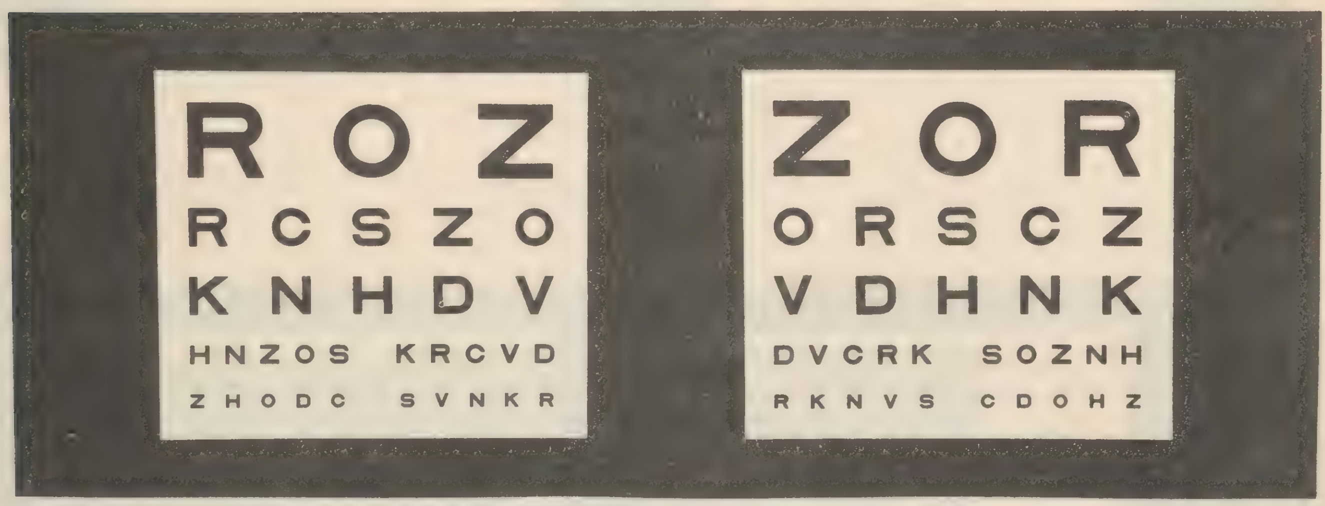



FIGURE 3

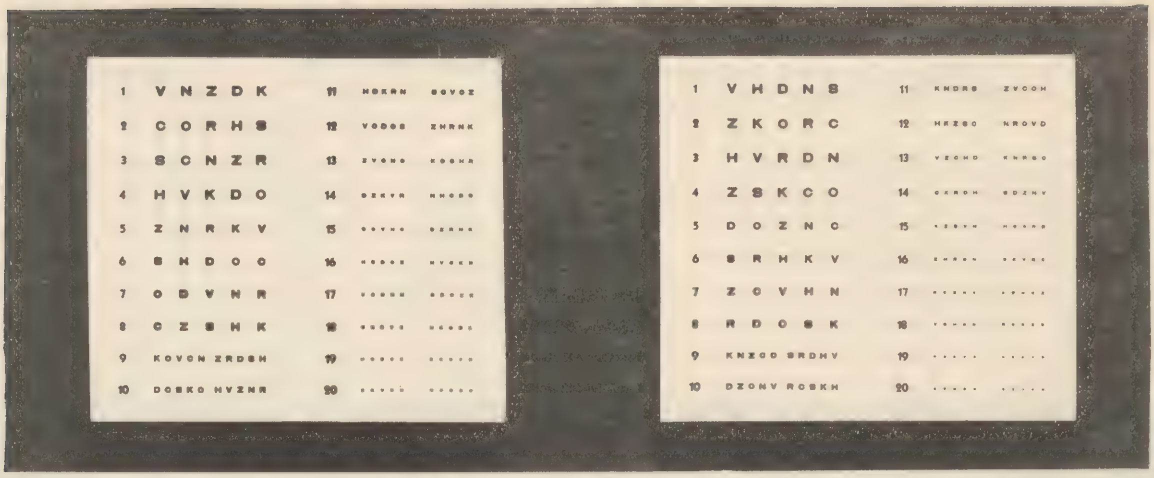


FIGURE 4

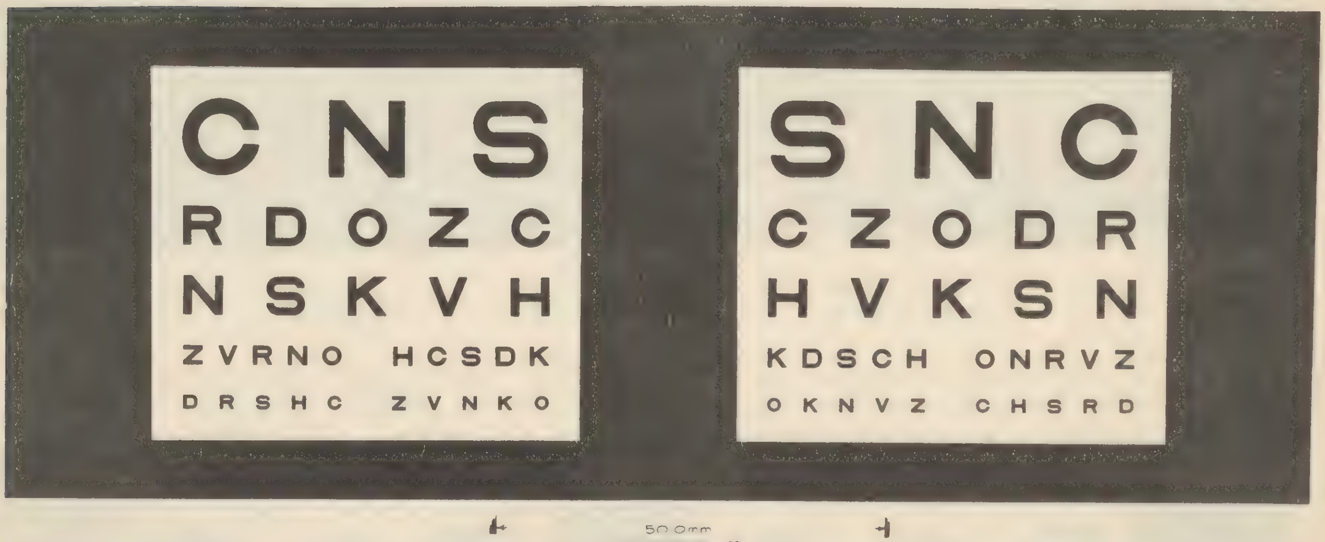



FIGURE 5

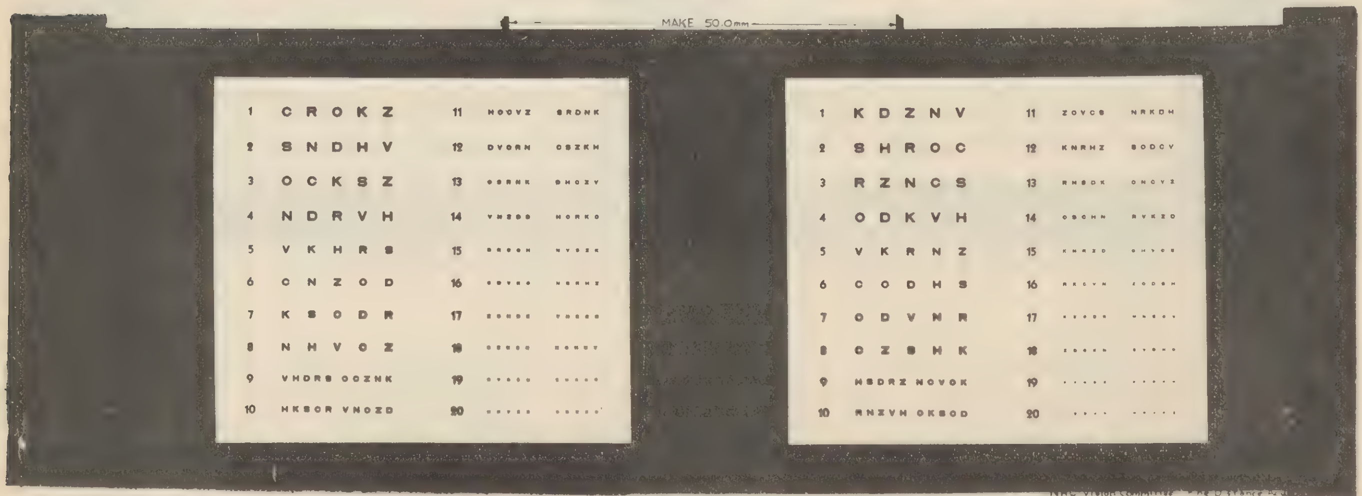



FIGURE 6


FIGURE 7


FIGURE 8

FIGURE 9

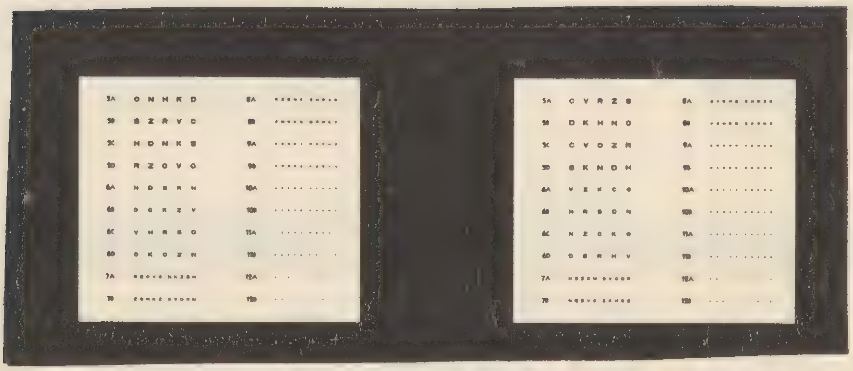


FIGURE 10

| | |
|---|---|
| H | H |
| K | K |
| O | O |
| V | V |
| D | D |

FIGURE 11

Dr. Gibson made what he termed a brief plea for the question of validity of acuity tests. Dr. Gibson stated that it is clear that the Armed Forces need a screening test which may be readily administered, but that the Vision Committee should guard against giving the impression that we know what we are measuring when we say we are measuring visual acuity. He stated his opinion that what we really wish to measure is "perceptual efficiency," but that we do not at present know what this quantity might be. Dr. Gibson emphasized that there is a real need for continuation of theoretical research in the area of perception as applied to what is called visual acuity.

Dr. Uhlaner asked whether the working group plans to recommend that the test being forwarded to the Services will need standardization or that it is desirable that they be standardized. Dr. Uhlaner stated that he had no idea what the rejection rate would be with the new visual acuity test as compared with the current rejection rate employing the wall type test.

Dr. Sloan asked the Chairman's permission to spend a few minutes discussing the problem of the selection of a test of acuity. A summary of her remarks is presented below:

## Some Comments on the Selection of a Visual Acuity Test

Louise L. Sloan

Of the several tests incorporated in this vision tester, that for acuity is probably of the greatest importance throughout all branches of the Armed Services. Because correcting glasses cannot conveniently be worn in many situations, tests of uncorrected acuity are particularly important. Since no military standards at the present time require better than 20/20, the chief function of the acuity test is to measure impairment caused by uncorrected errors of refraction. Every healthy eye should have an acuity of at least 20/20 when refractive error is corrected. When acuities in the range from 20/20 to 20/400 are measured, we are not testing individual differences in retinal resolution, but rather differences in optical resolution. Simple test objects such as two points, two parallel bars, checkerboards, etc., while ideal for testing retinal resolution are not the best tests for detecting blurring of the retinal image which may affect only a simple meridian. For this purpose complex test targets are needed which cannot be recognized unless retinal image is clearly focussed in all meridians simultaneously. Emsley says that the test objects should be "of as complicated form as is clinically convenient in order to subject the eye to a test comparable with the varied tasks imposed upon it in every day life. At the same time, however, the test should permit of simple questions to and simple answers from the subject, and his answers should be capable of rapid checking." The Landolt ring, though apparently simple in form, can perhaps be classed as a complex test object because poor focussing in any one meridian interferes with correct location of the gap in the ring. One practical objection to this type of target is that extreme alertness is required of the examiner in checking the responses. When the threshold level is approached, the typical subject starts off saying up, down, left, for example, and then without warning to the examiner decides to begin at the beginning again, so that the examiner, if not alert, becomes hopelessly lost in trying to check the correctness of the subject's responses. This probably explains the fact that,

although Landolt ring tests have been used successfully in many research studies, and have been recommended by various committees as a standard test, they have nevertheless not been used in routine clinical tests.

In 1930 the Committee on Optics and Physiology of the A.M.A. recognized the practical advantages of letters as compared with Landolt rings, and recommended that the difficulty of the letters be standardized experimentally by comparison with Landolt ring test objects, rather than by acceptance of the Snellen principle. It was hoped by Snellen that letters constructed according to his now well-known principle would be all of equal difficulty. Numerous investigators in the past 100 years have shown that this is by no means true. Rigid application of the Snellen plan that all components of the letter be separated by a unit angular difference, requires the introduction of serifs and other modifications in the familiar form of the letters and can produce letters which vary markedly in difficulty because the unfamiliar form of certain letters prevents easy recognition.

It is for this reason that we have used ordinary single stroke letters without serifs. The as yet unsolved problem of obtaining different letters of equal difficulty has been circumvented by using the same 10 letters on each successive line of the chart. Regardless of individual differences in difficulty of the letters, the average difficulty must increase with decrease in size of letters.

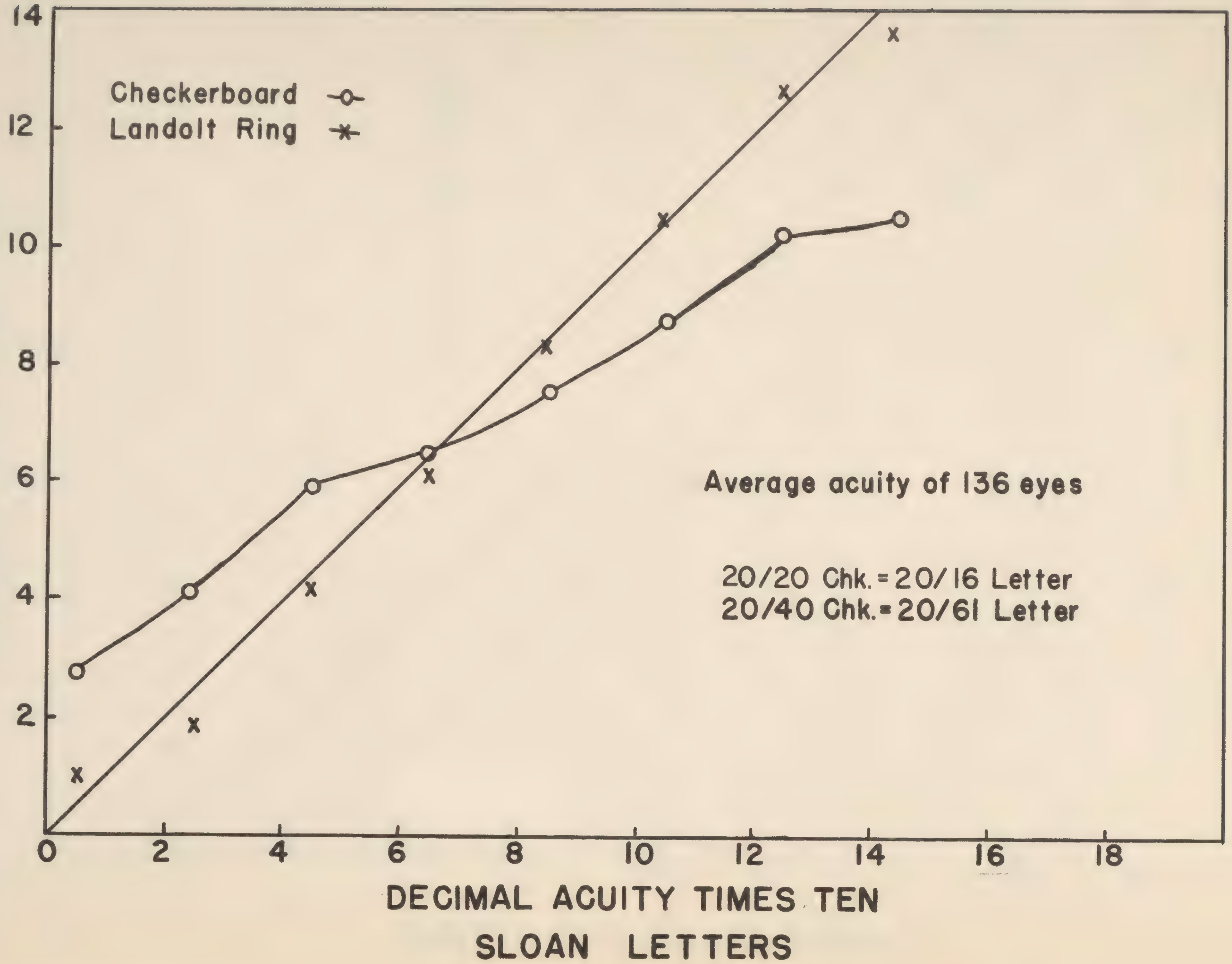
Someone, I am sure, is going to ask whether his acuity test will fail a higher or a lower percentage of examinees than are failed by tests now in use. It is difficult to answer this question because "tests now in use" must include all the different commercial acuity charts authorized by the Army, Navy and Air Forces. It is true that change in the character of the test object can materially affect the percent of individuals who are qualified. Slide 1 presents data from a New London report which shows that the New London Letters are definitely more difficult at all levels than the letters on two commonly used charts sold by Meyrowitz; i.e., the ones starting with O and with L at the 20/200 level. The greater difficulty of the New London Letters is perhaps because of their more unfamiliar form. It is obvious that we can never make any progress in improving tests of visual acuity if it is required that the new test agree perfectly with each of the many tests now in use. In the absence of any other reliable standard, we might accept the recommendations of the Committee of Ophthalmologists I mentioned and evaluate the new test chart in terms of one composed of Landolt Rings. Slide 2: In this graph the x's show the average Landolt Ring acuity for each level of letter acuity, and, as you can see, the experimental points are close to the line representing complete identity between the two tests. These data are for only 136 eyes, and we would like to have many more cases before making an elaborate statistical analysis. Whether we get more data depends upon Dr. Uhlaner, Dr. Scobee, and the two Navy stations who have promised to cooperate and were provided with the necessary test material last May.

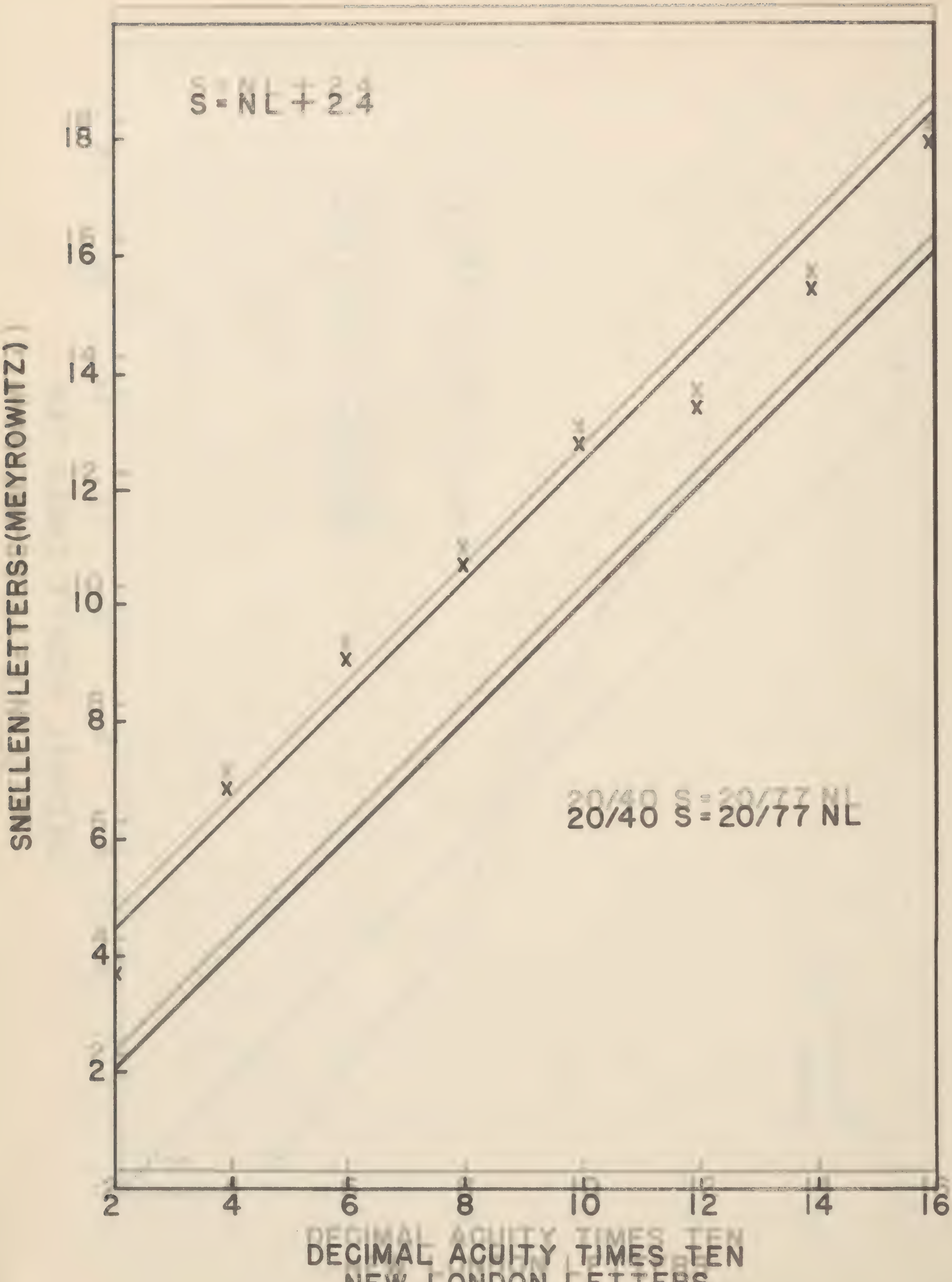
This same slide gives some preliminary data on the relationship between letter and checkerboard acuity and illustrates one of the reasons that we are unwilling to recommend the checkerboard test at this time. The circles show the average checkerboard acuity for each level of letter acuity, and, as you can see, there is by no means a one-to-one relationship such as we found between Landolt Ring and letter acuity. The relationship as shown indicates that a checkerboard acuity of 20/40 equals about 20/60 letter acuity, a checkerboard acuity of 20/20 about 20/16 letter acuity. I do not believe, however, that

we can establish the true relationship between checkerboard and letter acuity from these data, since I suspect that it may be different for subjects with simple astigmatic and simple spherical errors. As yet there are not enough subjects in these two groups to analyze them separately.

This particular letter test is not necessarily the final answer to the problem. If the Vision Tester is adopted, any one of the individual tests can be changed at any time merely by substituting a different slide.

Dr. Blackwell proposed that the recommendations made to the Armed Services include the idea that cut-offs must be established by the Services in order for the screening examination to be employed for purposes of classification. This suggestion appeared to meet with the approval of the consensus of members present.


14
12
10
8
6
4
2
0
2
4
6
8
10
12
14
16
18
Checkerboard
Landolt Ring
Average acuity of 136 eyes
20/20 Chk. = 20/16 Letter
20/40 Chk. = 20/61 Letter
DECIMAL ACUITY TIMES TEN
SLOAN LETTERS



S = NL + 2.4
20/40 S = 20/77 NL
SNELLEN LETTERS-(MEYROWITZ)
18
16
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16
DECIMAL ACUITY TIMES TEN
NEW LONDON LETTERS

PROPOSED ARMED FORCES COLOR VISION TEST FOR SCREENING

DEAN FARNSWORTH

1. It is well agreed that a dichotomy exists between the trichromatic color vision found in nine-tenths of the male population (commonly termed "normal") and the reduction types of color vision (commonly termed "defective"). The committee conceived the purpose of a screening test to be the segregation of the color normals from the color defectives without further attempts at the screening level to differentiate types or degrees within the two classes. It was further agreed to recommend a certain selection of polychromatic plates with standard illuminant since it has been found technically impossible, to date, to make a satisfactory test for incorporation in a machine test for acuity.

2. Contrary to common impression, a set of pseudo-isochromatic plates is a delicate instrument. Because the plates look simple and can be handled like a book, most people do not realize that their production requires as much technical skill as does a micrometer or spectroscope and that a similar order of accuracy is required in their administration and interpretation. However, they constitute the only type of screening test which is immediately available in the event of mass mobilization.

3. There is only one stock of these plates available in the United States, and that consists of the excellent reproductions of certain Stilling and Ishihara plates made by the Beck Engraving Company under the supervision of Mr. Henry Yuhas. The American Optical Company acted as distributor, and the plates are therefore known by their name, even though they had no technical or scientific connections with their preparation. It is true that the reproduction was sound, but the diagnostic values of the original plates varied from very good to very bad indeed. (There was even one plate which was failed by more normals than by color defectives.) It became apparent at the outset that the manner of administration and interpretation required careful control, and that a selection had to be made from the total. Between 1942 and 1946 there were at least 11 known selections by American, Canadian, and British military services and investigators*.

4. Early in 1943, Navy representatives requested that Dr. Judd make an evaluation of the A.O. collection of 46 plates. Following inter-Service discussions by mail and a meeting on March 6, 1943, with the Inter-Society Color Council Sub-Committees on Color Blindness Tests, Dr. Judd communicated his analysis to Commander Shilling on March 23, 1943, with the comment that "Perhaps this reply may form the basis for discussions leading to the preparation of an abridged color vision test meeting the needs of both the Navy Department and of the Army Air Corps." It did, and seven and one-half years of discussions have come to a head in this report.

5. It is specified that the tests shall be administered under an Easel Lamp of the type designed at the New London Laboratory in cooperation with the Macbeth Daylighting Company, recommended by the Vision Committee Sub-Committee on Color Vision and approved by Admiral Swanson, Surgeon General of the U.S. Navy. It is now carried in the Armed Services Materiel Catalog as Stock No. 3-456-635. Photograph are working drawings as shown in Figure 1; functional specifications are given at the end of the paper.

*The bibliography is extensive and will not be repeated in this paper. Most of the references can be found in "Compilation of Research on Abridgement and Administration of the A.O., 1st Edition Pseudo-Isochromatic Plates," Farnsworth & Kimble, Color Vision Report No. 14, Medical Research Laboratory, New London, 9 Dec 1946.

The remaining paragraphs summarize the reasons for the plate selection, the scoring and the validity to be expected from the score.

## PLATE SELECTION

6. One demonstration plate and fourteen diagnostic plates have been selected by the committee of Dr. Louise Sloan, Dr. Deane B. Judd and myself. These are exhibited in their proposed binder which is designed to fit the Easel Lamp. Let us examine to what extent these fourteen plates meet various criteria which have been proposed for plate selection.

7. The first and simplest of these criteria was used by Captain C.W. Shilling and Dr. John David Reed of the New London Laboratory. They made the assumption that those plates were best which were missed by the fewest number of normals, and that those plates were best which were missed by the greatest number of color deficients. The plates were ranked and the ranks summed. Applying this system to a sample of 736 normals and 212 defectives later tested at New London, it is found that the 14 Armed Forces plates are included in the highest ranking 22 plates by the Shilling-Reed criterion.

8. This technique was refined in Dr. Judd's report whereby he ranked the plates according to a score consisting of the percentage of errors made by deficients on each plate minus the percentage of errors made by normals. For a perfect plate the score would be 1.; for a useless plate the score would be 0. Applied to New London data, Dr. Judd's rank order includes in the first 18 plates all those which appear in the Armed Forces test, as shown in the ninth column of Figure 2.

9. This technique also can be used to predict the average number of plates which would be expected to be missed out of a given selection of plates. The actual calculation of this system applied to the plates in the Armed Forces Color Vision Test is shown in Figure 2. In the next to last two columns we find that normals would be expected to average 0.66 errors and color defectives would be expected to average about 11.0 errors. Some years ago, we did an extensive study on a population of 398 people, and from these Miss Helen Paulson has calculated retroactively the actual errors on the Armed Forces plates as compared to the predicted errors. Dr. Judd's formula of 1943 proved remarkably reliable as shown by the actual errors of just 0.7 for normals and 12.6 for defectives.

10. One of the reasonable criteria for the selection of plates is based on the frequency with which a plate does not misclassify normals and does not misclassify defectives, taking into account the additional fact that misclassification of normals is more serious than misclassification of defectives. (This will be especially true in the proposed use of these plates. As the system works, misclassification of normals will not be rectified, misclassification of color defectives will be rectified during examinations for their special duties.) Using the Green and Sloan system, weighted triply for normals, Figure 3 shows the misclassification of all of the 46 American Optical plates. (Armed Forces plates are represented by heavy dots). It will be seen that all plates selected for the Armed Forces test fall inside the zone which includes the best 23 plates by this criterion.

11. Sloan and Green also proposed that a plate which would not mislead the investigator more often proportionately in one direction than the other would be more satisfactory. Their technique applied to the Armed Forces plates is presented graphically in Figure 4 where it is seen that all but two of the plates fall within

a minimal sigma of the difference of misclassification which includes the best 16 plates.

12. Let us look at the final result. As Dr. Sloan says, we have proceeded by trying to eliminate all plates which have proved unsatisfactory by trial at Randolph Field and New London. There remains a fringe of moderately weak plates, such as numbers 9, 10 and 43, some of which must be included to lengthen the list enough to increase the reliability of the test even though it decreases the validity. We find the selection confirmed by similarity to that made by clinical methods by Hardy, Rand and Rittler and approved for unrestricted sale by the Inter-Society Color Council. Referring to the plates in the Armed Forces selection, the New London Color Vision Report No. 14 stated, "We have now examined the plates according to four different criteria...... It is reassuring to find that 14 plates are included in the most diagnostic 22 by all four methods." Referring back to Figure 2, we also note that the plates which rank highest by these statistical methods, and all plates which were selected by a majority of 11 international authorities, are included in the Armed Forces selection.

## SCORING

13. If we had now produced a perfect set of plates all normals would make none or only a few errors and all defectives would make more than that number, so that, properly administered, there would be no misclassification. We have analyzed the responses of a population of 398 highly tested people to the plates in the Armed Forces selection with the result seen in Figure 5.

14. Using a cutoff of between four and five errors, we find one out of 100 defectives misclassified and 0.6%, or less than one out of 100, normals misclassified. This is extremely good. It is better than that found by Dr. Ingeborg Schmidt* in her trial of the comparative validity of the Hardy, Rand, Rittler selection, the Sloan USAF selection, and the Farnsworth-Kimble selection. However, this particular sampling was obtained under almost ideal administration by Dr. Reed, and we can have no hope that it will be quite this good under less than ideal conditions. At its best it will misclassify about 1% of a male population; it can be as bad as its administration. We can only say that we believe the instrument is the best procurable from present materials.

## VALIDITY

15. We have seen that the proposed Armed Forces test promises a potential validity as high as 99% as a screening test to separate normals from defectives. Unfortunately, it is commonly believed that the number of plates failed is an indication of degree of defect. It seemed necessary to put a disclaimer of this in the instructions: "purpose. 10. This test of red-green deficiency is for screening purposes only. It does not classify type of red-green defect, and the number of plates failed over 5 does not indicate reliably the amound of deficiency."

16. Figures 6 and 7 have been prepared by Miss Paulson, Technician in charge of color vision testing, to show the correlation of number of plates failed on 14 polychromatic plates with the extent of defect as measured by our test battery. We do

* "New tests for Examination and training of Color Vision," Project No. 21-02-042, Report No. 2, USAF School of Aviation Medicine, Randolph Field, April 1949.

not, of course, have comprehensive data on a population who have been given the proposed Armed Forces plates, and it is therefore necessary to make this analysis against our laboratory test of 14 special plates (unpublished) called the Navy 2nd Edition A.O. However, since this group of plates is superior to the 1st Edition, we would expect an even higher correlation between classes and number of plates missed, if such correlation exists. Deutans and protans are examined separately. Class II is mildly defective color vision, Class III moderate, Class IV severe, Class V dichromatic. It is evident that the correlation with plate errors is low, that there is much overlapping of classes, and that prediction of degree of deficiency from the number of plates failed would be quite uncertain.

## The Following Recommendations are Made for

## MASS TESTING OF COLOR VISION

I

1. The Armed Forces-NRC Vision Committee recommends that the test herein described be designated the "Armed Forces Color Vision Test" and be utilized for general testing of color vision in the Armed Services. It is recommended that general color vision tests at present used in the Armed Forces be replaced as soon as possible by the test described herewith.

2. The described test is a selection of pseudo-isochromatic plates which has been made as the result of demonstrated superiority of these plates in Air Force and Navy experimentation and use. In addition, the selection of pseudo-isochromatic plates at present utilized in the Armed Forces is subject to malingering since the plates are available to the general public. The selection herein referred to it not available to the general public.

3. The recommended test consists of 15 plates, (a demonstration plate and 14 test plates) prepared in a loose-leaf binder. The test shall be performed at all times under illumination from Macbeth-New London Easel Lamp ADE-10 or its equivalent. The demonstration plate shall always be shown first but the order of the test plates shall be varied from time to time so that candidates cannot anticipate the correct answers on the test. The passing score shall be 10 of the 14 test plates. A record of pass or fail shall be made for each candidate.

4. Because of the demonstrated stability of color vision, the general test of color vision need not be repeated routinely. Candidates failing the test shall be informed of their failure and cautioned to avoid dependance upon color cues in their performance of military duties.

5. If desired, suitable adjunct tests of color vision may be given in connection with selection for job specialties, in order to determine the degree of color deficiency of candidates failing the general test.

6. Because at least 8% of the male population is color defective, every effort should be made in the design of equipment and job specification to augment color cues by other cues, such as identifying shapes.

II

## DESCRIPTION OF ARMED FORCES

## COLOR VISION TEST

1. The test shall consist of 15 plates of which one is a demonstration plate. The words "demonstration plate" shall be printed on the plate.

2. The 14 diagnostic plates shall be the following:

| Plate Number | Normal Response |
|---|---|
| Demonstration | |
| 25 | 12 |
| Diagnostic | |
| 6 | 6 |
| 8 | 42 |
| 9 | 56 |
| 12 | 57 |
| 14 | 75 |
| 19 | 5 |
| 20 | 3 |
| 23 | 56 |
| 24 | 27 |
| 27 | 89 |
| 29 | 86 |
| 41 | 15 |
| 42 | 74 |
| 43 | 47 |

The plate numbers are listed according to the plate numbers in the First Edition of the American Optical Company "Pseudo-Isochromatic Plates for Testing Color Vision."

III

## DESCRIPTION OF EASEL LAMP FOR

## HOLDING AND ILLUMINATING PSEUDO-ISOCHROMATIC PLATES

1. The illumination shall be incident upon the center of the plates at approximately 45°.

2. The viewing angle shall be normal or approximately 90°.

3. The source of illumination shall be a 110 to 120 volt incandescent frosted lamp.

4. The color temperature of the lamp shall be modified by a Corning-Macbeth filter, or equivalent, so as to approximate the energy distribution of illuminant "C".

5. The filter glass must meet the following requirements: (a) it must filter incandescent illuminant A, 2848°K, to a color no yellower than a color temperature

standard bulb and standard filter assembly emitting light of 6500° color temperature and no bluer than such an assembly emitting light of 7500°K color temperature. (b) The ratio of the spectrophotometric transmission of each filter at 670 millimicrons to that at 700 millimicrons must be 0.9 or higher.

6. A switch shall be provided in the fixture.

7. The holder shall permit the book to incline backward at approximately 30° from the vertical.

8. A recess shall be provided in the base, deep enough to retain the board covers while permitting free swing for the pages.

9. An opening shall be left at the center of the base as a relieve for the back binding and a similar relieve shall be provided in the center of the upper support for the binding.

10. A six to eight foot extension cord with plug cap will be provided.

11. The base shall be protected with felt.

12. Structural parts shall be made nonadjustable.

13. The filter shall be replaceable in case of breakage and removable to provide for lamp replacement.

14. The incandescent source shall be so enclosed and shielded that no light unmodified by the filter can escape.

15. When measured in the plane of the opened book, every point four inches from the center of the book shall receive not less than twenty foot-candles of illumination nor more than thirty foot-candles.

## IV

## PROPOSED DRAFT FOR INSTRUCTIONS

### For
### Armed Forces Color Vision Test

### PHYSICAL ARRANGEMENTS

1. The Armed Forces Color Vision Test consists of 1 demonstration plate and 14 test plates in a ring binder. The covers should be kept closed when the test is not in use.

2. The test shall be administered under the Easel Lamp listed in the Armed Services Catalog of Medical Materiel:

> Stock No. 3-456-625, Lamp, Color Vision Test, daylight filter, with easel for supporting test plates.

3. The Easel Lamp should be placed on a table or shelf so that the applicant's line of sight is at right angles to the plates and so that his eyes are at a distance of

approximately 30 inches (plates just out of arm's reach). The applicant should not face an open window or other strong light. Nearby incandescent lights should be shielded so that they do not illuminate the plates. Nearby window shades should be drawn.

## ADMINISTRATION

4. Only one applicant should be in the test room at a time; other applicants should not be allowed to watch or listen.

5. The examiner shall instruct the applicant to "please read the numbers." The examiner shall not give other instructions and shall not ask other questions. The applicant is not allowed to trace the patterns or touch the test plates.

6. The demonstration plate must be shown first (a red "12" on a blue background). All of the remaining 14 plates are then shown. About 2 seconds should be allowed for response to each plate. If the applicant hesitates, he should be asked again to "read the number"; if he fails to respond, the examiner turns to the next plate without comment. Whenever the test is given, the entire test must be given, and each plate must be shown but once.

7. With the exception of the demonstration plate which is always first, the examiner must change the order of the plates frequently. The change should be made at least weekly, and oftener if there is suspicion that the numbers have been learned in serial order by applicants.

## SCORING

8. If 4 or less responses to the 14 test plates are incorrect, entry shall be made in the applicant's record, "Color Vision, NORMAL." If 5 or more incorrect responses are given, including failure to make responses, entry shall be made in the applicant's record, "Color Vision, DEFECTIVE." The candidate should be informed of his failure and cautioned to avoid depending upon color cues in his performance of military duties.

9. The demonstration plate is not considered in scoring. In plates with two-digit numbers, an incorrect response to either is a failure for the plate.

10. The interpretation of error score holds only when the test is administered under the standard source of illumination, standard distance and standard timing.

## PURPOSE

11. This test of red-green deficiency is for screening purposes only. It does not classify type of red-green defect, and the number of plates failed over 5 does not indicate reliably the amount of deficiency.

DISCUSSION:

Lt. Rand commented on the fact that the selection of plates in the proposed color vision test included some of the plates which are currently used in other selections available to the general public. He asked whether this was not at variance with the general principle adopted at the July 19 meeting.

Cdr. Farnsworth replied that it was impossible not to select plates which are a part of one or another of the commercial selection, because there are a

limited number of valid plates in existence. He noted that the overlap between the present selection of plates and the selection made by Hardy, Rand and Rittler is not great, and that, therefore, it should be relatively impossible for malingering to occur.

Lt. Rand then asked whether the working group had considered using dual number plates in the color vision test.

Cdr. Farnsworth replied that the use of dual number ("reversible number") plates is the one positive way to avoid malingering, but he stated that the selection of an adequate number of reversible number plates to screen the various kinds of color defectives would involve a long and tedious research which might be expected to require years of work. It would be possible to develop such a test, but it would not be possible to do so to serve the immediate purpose of the visual screening examination.

Dr. Sloan commented that it seemed to her there were a number of good practical reasons why the new test should be adopted by the Armed Services. Dr. Sloan listed these as follows:

1. Since the 17-plate "abridged AOC" which is now the official Air Forces test, and the 20-plate test now used by the Navy have 16 plates in common, it seems logical that in order to simplify procurement they adopt a single test satisfactory to both services.

2. The new test omits the plates requiring tracing of paths. This will simplify administration of the test, save time and eliminate the camel's hair brush with which the examinee traces the path.

3. In addition to omission of the plates containing paths, the proposed test differs from that now used by the Navy only in that four numeral plates are also omitted.

4. The new test differs from the "abridged AOC" now in use by the Air Forces only in that two paths and two numeral plates are omitted and one plate (No. 9) not previously used is added.

5. The commercially-available Hardy, Rand, Rittler set of 20 plates uses 11 plates which are also included in the proposed test. Since it has 7 plates which are <u>not</u> in the 14-plate test, and the latter has 3 plates <u>not</u> in the Hardy, Rand, Rittler series, the two tests are sufficiently different to prevent malingering.

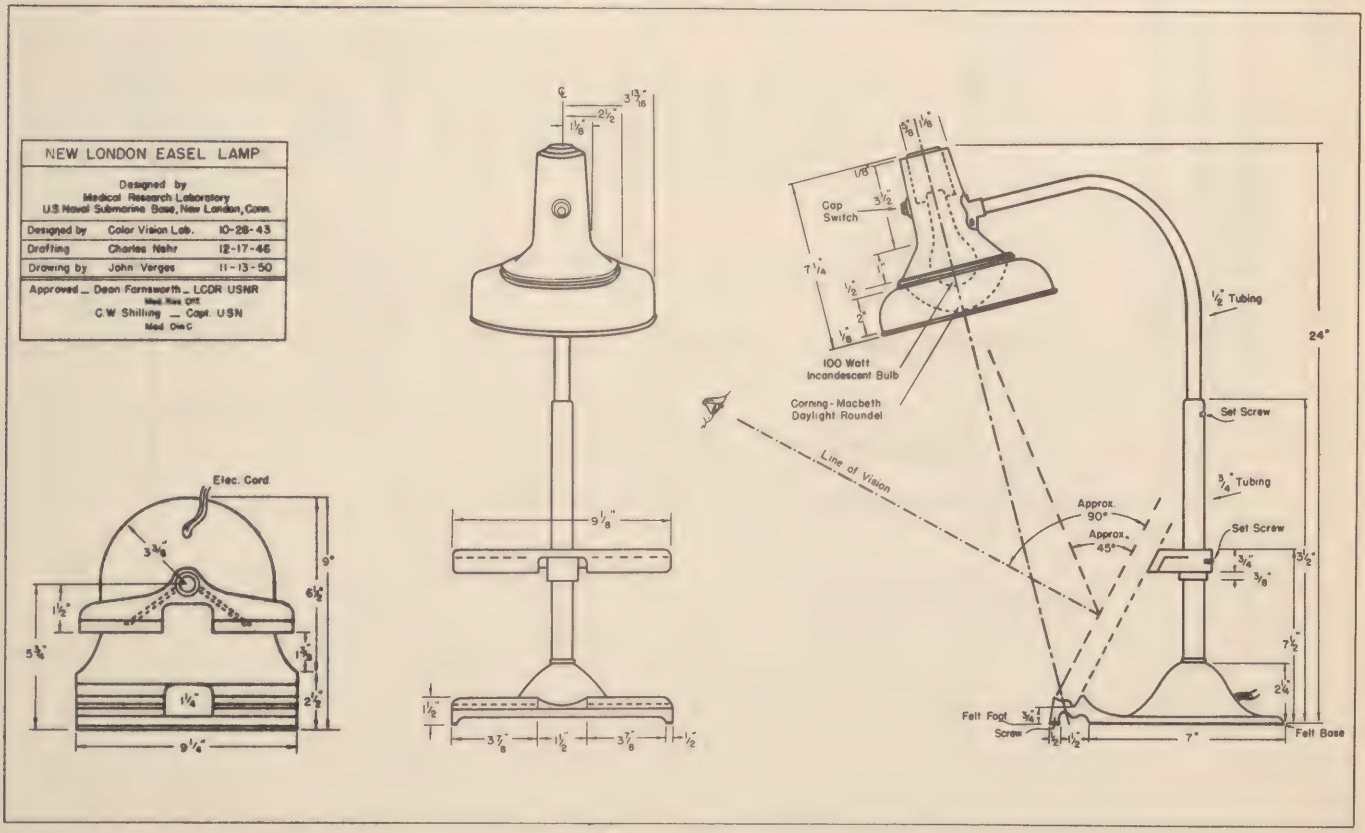

NEW LONDON EASEL LAMP
Designed by
Medical Research Laboratory
U.S. Naval Submarine Base, New London, Conn.
Designed by Color Vision Lab. 10-26-43
Drafting Charles Nehr 12-17-46
Drawing by John Verges 11-13-50
Approved _ Dean Farnsworth _ LCDR USNR
C.W. Shilling _ Capt. USN
Med. Oin C
Elec. Cord
Cap Switch
100 Watt Incandescent Bulb
Corning - Macbeth Daylight Roundel
½" Tubing
24"
Set Screw
Line of Vision
¾" Tubing
Approx. 90°
Approx. 45°
Set Screw
Felt Foot
Screw
Felt Base
7"
9¼"
9⅛"

Figure 1

Figure 2

COMPUTATIONS OF AVERAGE NUMBER OF ERRORS
TO BE EXPECTED FROM ARMED FORCES TEST
COMPARED WITH EXPERIMENTAL RESULT.

| Plates selected by: all methods | Statistical method | majority of 11 authorities | Plate Number | Correct Response | Percent who missed plate: Normal | Percent who missed plate: Def'nt | % errors defn'ts minus % errors normals | Rank from Previous Col. | Predicted: Average no. expected to be missed out of given no. of plates by Nor's. | Predicted: Def's. | Actual: Errors on Armed Forces Test Nor's. | Actual: Def's. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | X | X | 19 | 5 | .005 | .880 | .875 | 1 | .005 | .880 | | |
| X | X | X | 27 | 89 | .020 | .890 | .870 | 2 | .025 | 1.770 | | |
| X | X | X | 20 | 3 | .030 | .890 | .860 | 3 | .055 | 2.660 | | |
| X | X | X | 29 | 86 | .030 | .875 | .845 | 4 | .085 | 3.535 | | |
| X | X | X | 23 | 56 | .010 | .765 | .755 | 6 | .095 | 4.300 | | |
| X | X | X | 42 | 74 | .020 | .770 | .750 | 7 | .115 | 5.070 | | |
| X | X | X | 6 | 6 | .000 | .735 | .735 | 8 | .115 | 5.805 | N = 298 | N = 100 |
| X | X | X | 12 | 57 | .090 | .765 | .675 | 10 | .205 | 6.570 | | |
| X | X | X | 8 | 42 | .050 | .720 | .670 | 11 | .255 | 7.290 | | |
| X | X | X | 41 | 15 | .000 | .625 | .625 | 14 | .255 | 7.915 | | |
| | X | | 43 | 47 | .140 | .920 | .780 | 5 | .395 | 8.835 | | |
| | X | | 14 | 75 | .145 | .780 | .635 | 13 | .540 | 9.615 | | |
| | | X | 24 | 27 | .120 | .845 | .725 | 9 | .660 | 10.460 | | |
| | | X | 9 | 56 | .000 | .495 | .495 | 18 | .660 | 10.955 | .70 | 12.60 |
| | | | 40 | 65 | .225 | .890 | .665 | 12 | .885 | 11.845 | | |
| | | | 21 | 97 | .030 | .655 | .625 | 15 | .915 | 12.500 | | |
| | | | 10 | 27 | .070 | .645 | .575 | 16 | .985 | 13.145 | | |
| | | | 44 | 98 | .175 | .920 | .545 | 17 | 1.160 | 14.065 | | |

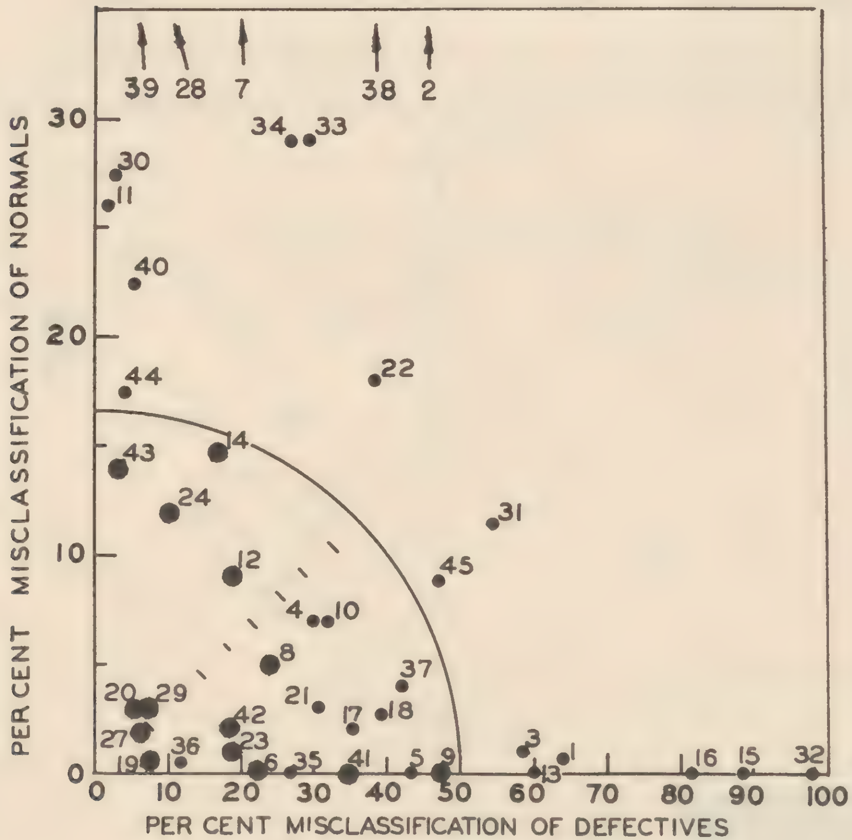



Figure 3

HIGHEST RANKING PLATES BY CLASSIFICATION OF NORMALS VS. DEFECTIVES.

Normals weighted by a factor of 3. Heavy dots indicate Armed Forces Selection.

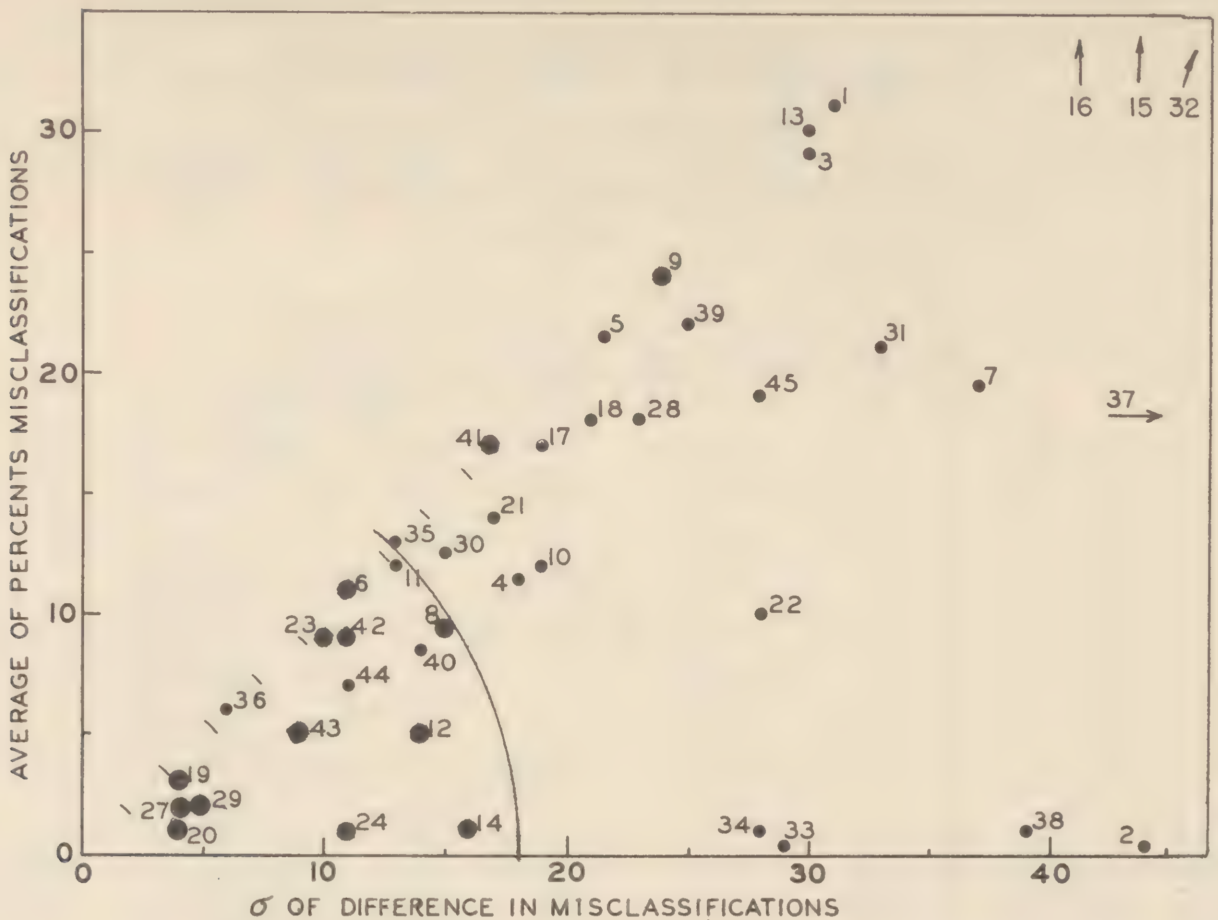



Figure 4

HIGHEST RANKING PLATES BY MINIMAL DIFFERENCE IN MIS-CLASSIFICATION OF NORMALS AND DEFECTIVES.

Minimal difference weighted doubly. Heavy dots indicate Armed Forces Selection.

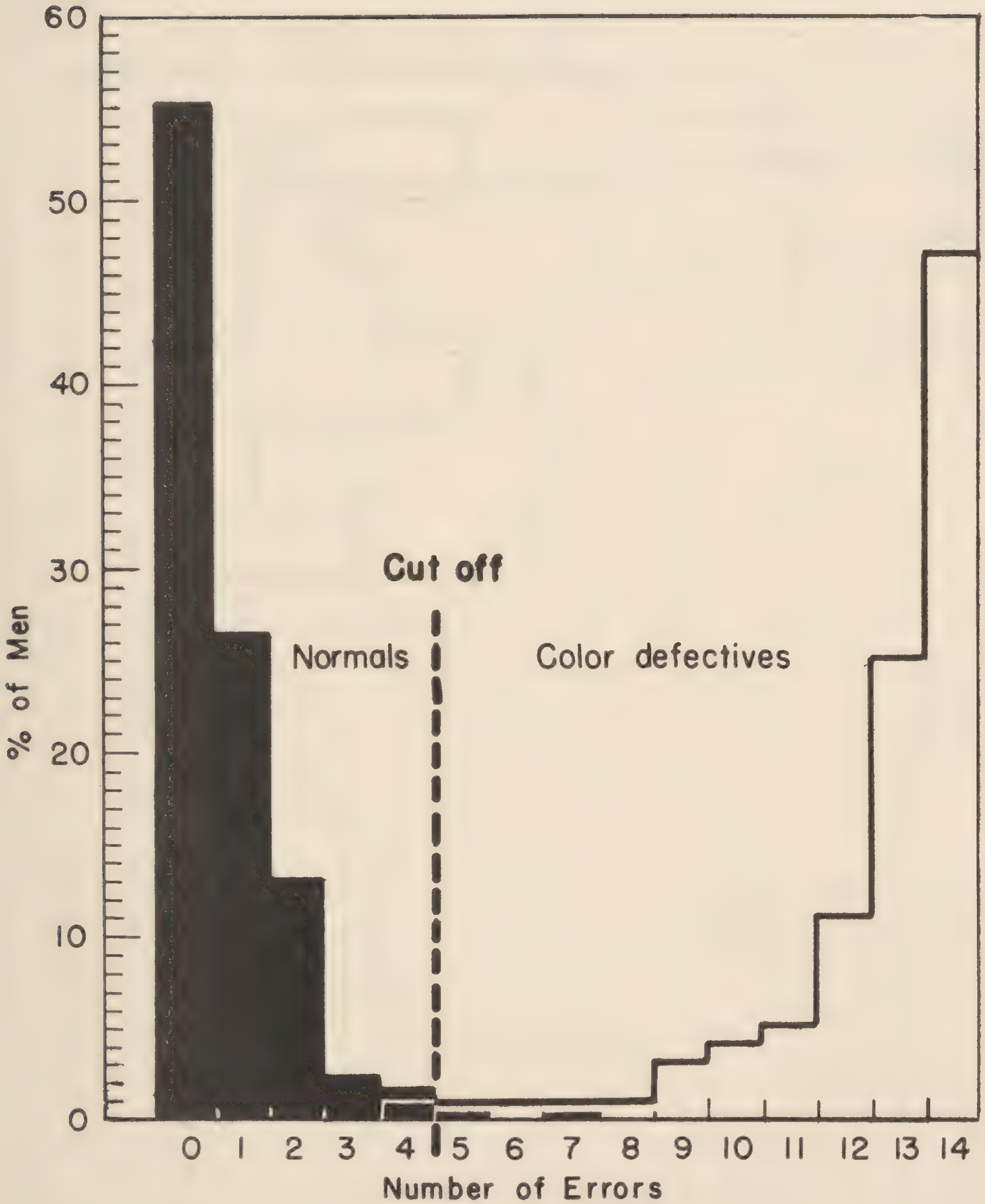



**Figure 5**

PERCENT ERRORS MADE BY 298 NORMALS AND 100 COLOR DEFECTIVES ON THE PROPOSED ARMED FORCES COLOR VISION TEST OF 14 PLATES

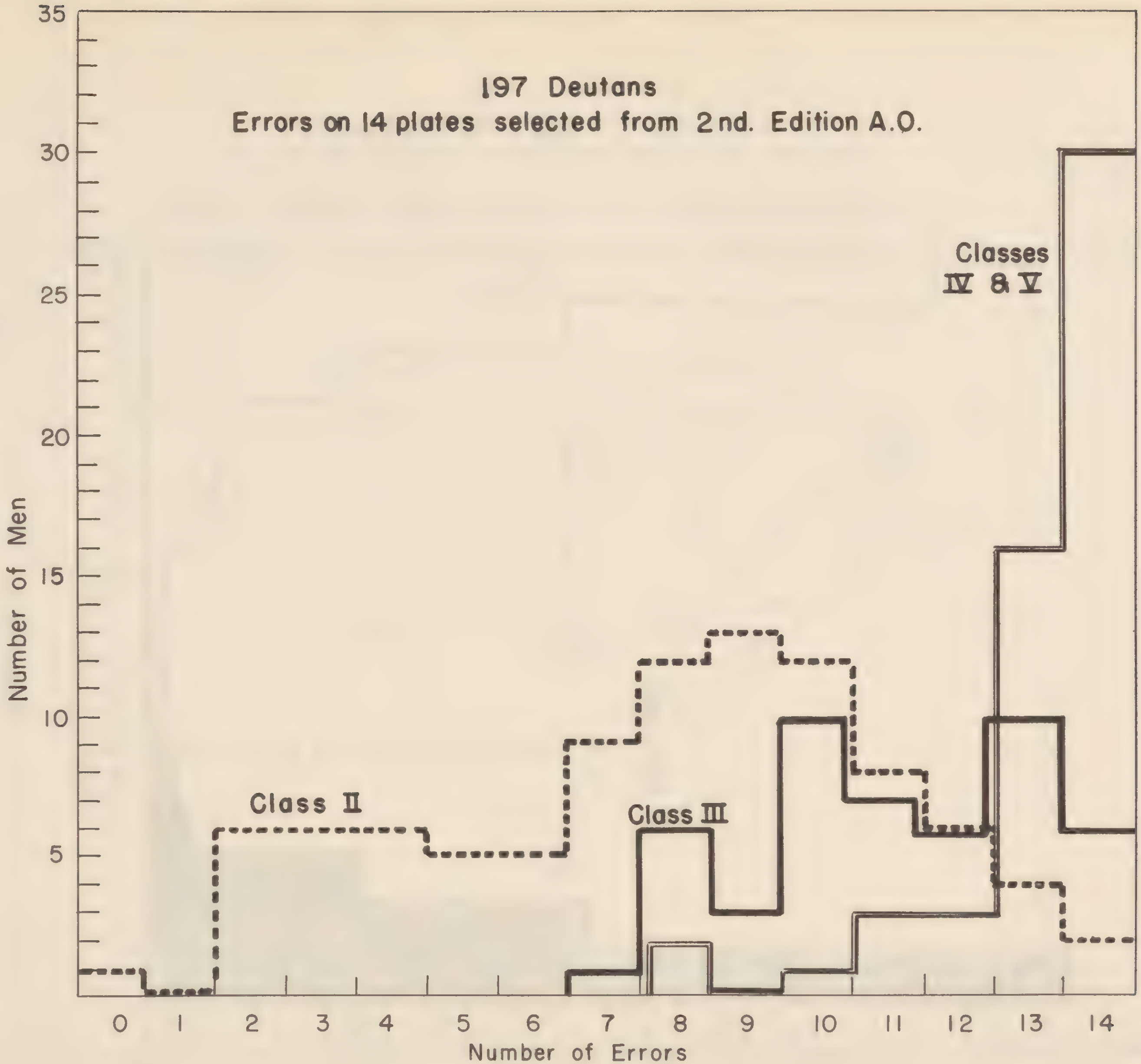



Figure 6

NUMBER OF ERRORS MADE BY DEUTANS ACCORDING TO CLASSES DENOTING DEGREE OF DEFECT.

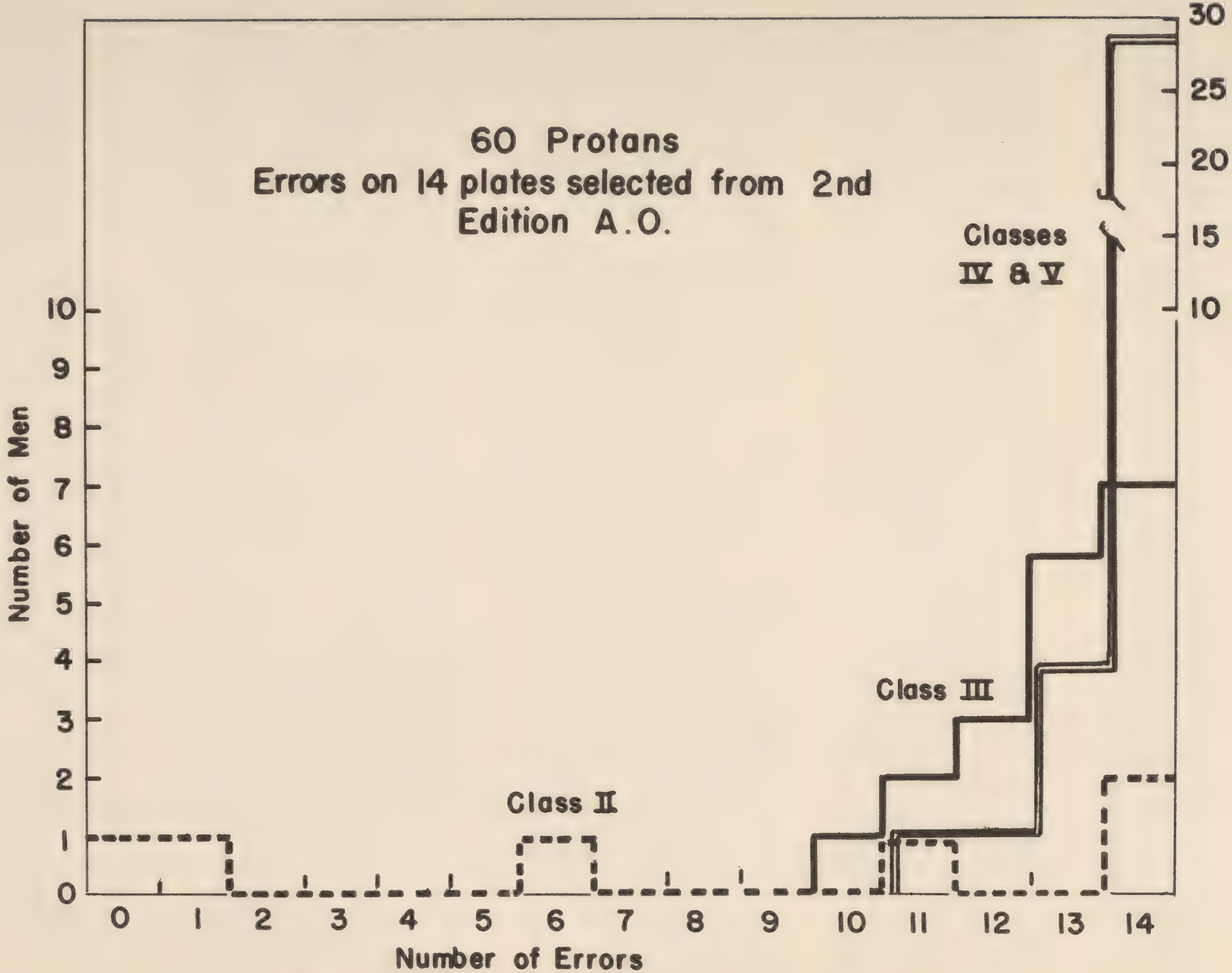



Figure 7

NUMBER OF ERRORS MADE BY PROTANS ACCORDING TO CLASSES

DENOTING DEGREE OF DEFECT

# Discussion of Experimental Conditions for Investigations on Visual Sensitivity and Discrimination proposed by the International Commission of Optics

Professor Stanley S. Ballard, who is Chairman of the U. S. National Committee of the International Commission of Optics, described that organization and its activities briefly. He then presented the tentative proposal for standard experimental conditions for investigations on visual sensitivity and discrimination as follows:

At the London meeting of the International Commission of Optics of July 1950, a special ad hoc committee was appointed to draw up a set of recommended standard practices applicable to experiments in physiological optics. It was noted that it is very difficult to make the desirable, close comparisons of data taken in various laboratories, since the details of experimental conditions are seldom, if ever, sufficiently similar. In order to correct this unsatisfactory state of affairs, it was suggested that a certain standard set of conditions might be employed at some time during experimental programs on vision and the efficiency of vision through instruments.

It should be emphasized that there is no desire to impose one set of experimental conditions to the exclusion of others. On the contrary, it is hoped that each laboratory will compare results obtained under the "standard conditions" with those obtained under different experimental conditions. For example, an observer might compare results obtained using the standard test with similar results obtained using the Landolt C. Comparison between the results obtained using the standard illuminant and others obtained using monochromatic light would also be very useful. The I.C.O., through its national committees, proposes to ask experimenters in this field to include, when appropriate, some experiments carried out under the standard conditions. These experiments will then provide a basis for a quantitative comparison with results obtained in other laboratories.

The working committee that was appointed to study this important subject consists of R. W. Ditchburn and W. S. Stiles of the United Kingdom, J. M. Otero of Spain, and A. Arnulf of France (Chairman). The preliminary draft of its recommendations is given here, in the hope that it will be carefully studied by all workers in experimental physiological optics. Comments, criticisms, and suggestions should be sent to Professor Ballard, Chairman of the U. S. National Committee of the International Commission of Optics who will collate all comments received and submit them to the U. S. National Committee. After consideration of the various comments and suggestions, the U. S. National Committee will submit a series of recommendations to the working committee of the International Commission, representing the opinion of U. S. Workers on the proposed international standardization.

## PROPOSED STANDARD CONDITIONS

1. Test Object

   (a) Shape

   Perception test: (i) Circular or square disc.
   (ii) Vertical line whose length subtends an angle of at least $5^{\circ}$ at the eye of the observer and whose ratio of length to breadth is at least 20.

Resolution test: A pair of one of the elements just described, with their centers separated by a distance equal to twice the width of one object. The limit of resolution is defined by the distance between centers (or axes of symmetry) of the two objects.

(b) Contrast

Definition: $C = \frac{B - b}{B}$, where B = brightness of background, and b = brightness of object.

Contrast $> 0$ and varying from 0 to 1 when the object is darker than the background.

Contrast $< 0$ and varying from 0 to $-\infty$ when the object is brighter than the background.

It is recommended that a logarithmic scale of contrast be used.

2. Spectral Composition of Light

The composition should be the same for object and background. White light should be used: I.C.I. Standard Illuminants A, B, or C. Illuminant A is preferred for low brightness experiments. If filters are used to reduce brightness, great care should be taken to obtain accurately neutral filters.

3. Background Brightness

The following brightnesses are recommended:

(i) $10^{-2}$ stilb = 9.3 candles/ft$^2$ = 29 e.f.c.*

(ii) $5 \times 10^{-6}$ stilb = $4.7 \times 10^{-3}$ c/ft$^2$ = $1.45 \times 10^{-2}$ e.f.c.

(iii) $10^{-8}$ stilb = $9.3 \times 10^{-6}$ c/ft$^2$ = $2.9 \times 10^{-5}$ e.f.c.

All brightnesses are to be measured on the photopic scale.

4. Field of View

The angle subtended by the background, at the eye of the observer, must not be less than

(i) $10^\circ$ for $10^{-2}$ stilb

(ii) $20^\circ$ for $5 \times 10^{-6}$ stilb

(iii) $30^\circ$ for $10^{-8}$ stilb.

* "equivalent foot candles"; numerically equal to foot-lamberts.

5. The Observer

The observer with seriously subnormal vision must not be used -- see definition of normal observer in Appendix 1.

Adaptation: One hour in artificial light (less than 2 foot-candles) followed by 40 minutes in darkness for adaptation to the lowest brightness ($10^{-8}$ stilb). Equivalent adaptation may be obtained using red light preadaptation, but exact conditions employed should be stated.

Period of an observation: 1 second when brightness is $> 10^{-5}$ stilb; 5 seconds when brightness is $< 10^{-5}$ stilb.

6. Method of Determining the Limit

It is recommended that experimenters determine a number of points on the "probability of seeing" curve. The limit is the point corresponding to 50% correct responses after correcting for the correct responses due to chance.

7. Correction of Vision

Day vision is to be corrected where necessary. The correction for night vision should be 1.5 diopters less than that required for day vision. Allowance should be made for loss of light in spectacles if these are not coated with reflection-reducing films. An observer who is emmetropic by day may be tested at low brightness without correction if the object is placed at a distance of 80 cm.

Appendix 1: Definition of Normal Observer

(a) Day Vision. A normal observer should be able to perceive, against a background of $10^{-2}$ to $10^{-3}$ stilb, a black spot whose visual angular diameter is 0.6 minutes of arc. For the same brightness he should be able to perceive a disc of diameter $2^{\circ}$ and contrast 0.01.

(b) Night Vision. The normal observer should be able to detect a black disc of visual angle $10^{\circ}$ against a background of $2 \times 10^{-10}$ stilb placed at a distance between $15^{\circ}$ and $35^{\circ}$ from the fovea, provided he is completely dark adapted.

Appendix 2: Fixation

Experiments may be carried out under conditions in which a trained observer is allowed to use whatever part of his retina he finds to be most sensitive, or a particular part of the retina may be selected by means of a fixation spot. If this is done, the observer must be instructed not to fixate continuously, but to allow his center of vision to traverse the region around the fixation spot. If it is desired to leave no initiative in this matter to the observer, a moving fixation spot may be used. The spot should be made to traverse a closed curve at a known speed. In all cases the exact conditions of fixation should be stated. When a red fixation spot is used, it should be placed at such distance that the eye is accommodated for the object, allowing for the chromatic aberration of the eye.

Professor Ballard referred to a recent paper, "New Neutral Glasses" by Chesterman and Harding in the May, 1949, Journal of Scientific Instruments which described some of the new Chance Bros - neutral glasses which approach the prewar Schlott glasses for neutrality. He then requested comments on the proposed standard conditions.

DISCUSSION:

Dr. Hulburt asked whether this question should properly come to the Vision Committee as a Committee, or whether it might not better be addressed to the individual members of the Vision Committee as individuals.

Dr. Ballard agreed that perhaps the question was largely one for individuals to consider, but emphasized the difficulty of knowing where to start. He stated that the Optical Society does not have any appropriate mechanism set up for establishing committees for considering this kind of request. Dr. Ballard commented that there were in the room a number of people who were not only interested in the problem but able to give him a great deal of assistance with respect to action on the proposed standards.

Dr. Crozier commented on the undesirability in general of imposing standard conditions upon research, stating that in his estimate this will undoubtedly lead to restriction of the possibilities of developing new theory. Dr. Crozier further stated that he would have no difficulty writing out about eight full pages of very serious objections to the particular standards proposed by the International Commission of Optics. He suggested that Dr. Ballard print the proposed standards in some journal, such as Science and call for suggestions.

Dr. Ballard thanked Dr. Crozier for the suggestion, and stated that it would be possible to print the standards in such a journal as Science. Dr. Ballard stated that he did not feel that he was personally very well qualified to evaluate such matters, and stated that he would like to have the Vision Committee "surround him" with a group of experts.

Dr. Riggs asked whether the standards were intended to be applicable principally to applied research or to theoretical research.

Dr. Ballard replied that the chief interest was in the theoretical rather than the applied research.

Dr. Riggs then stated that he would like to second Dr. Crozier's idea that various persons write their detailed criticisms to Dr. Ballard.

Dr. Blackwell commented that, in his opinion, the proposed standards might be considered to be in part a business of the Vision Committee, in addition to their being of interest to the membership of the Vision Committee as individuals. He stated that, particularly if the international situation remains unchanged, there will undoubtedly have to be expansion of research in military installations. If there is any value to the idea of standards at all, it would be very desirable for the Vision Committee to recommend that standard conditions be employed where possible in research undertaken at the newly expanded research installations. Dr. Blackwell stated his personal opinion that standard conditions are a poor substitute for theory, but that the problem of minor difficulties of procedure among laboratories makes it difficult to compare data, and in its own way retards the development of theory. Dr. Blackwell further commented that the proposal

made by the International Commission of Optics was that the standard conditions be employed only as a portion of a research program so that procedures which were more in line with the particular theoretical biases of particular individuals would not be ruled out, but it would be possible to compare the research in different laboratories in a more direct manner than is at present possible.

Dr. Grether commented that the standard for visual displays published by the Vision Committee were in some ways in conflict with the standards proposed by the International Commission of Optics.

Dr. Berens commented that such professional societies as the Illuminating Engineering Society and the American Committee on Optics and Visual Physiology of the American Medical Association should be contacted in addition to the Vision Committee.

Dr. Dimmick asked whether this request should not be referred to the American Standards Association. He asked whether the American Standards Association did not have a committee to which this could logically be referred.

Dr. Ballard commented that he had contacted Professor Sears of Committee Z-58 of the American Standards Association. There is a Subcommittee on Vision of which Dr. Blackwell is Chairman.

Due to the shortage of time, the discussion had to be cut short, but the Chairman expressed the hope that all interested persons would communicate direct with Dr. Ballard regarding this important international problem.

Abstract of the Movie Entitled
"Flight Recording of Pilot Eye Movements"

Walter F. Grether

Dr. Grether presented a movie which had been produced by professional motion picture technicians to summarize the research conducted at the Aero Medical Laboratory on the problems of eye movements of pilots, particularly in landing operations. Dr. Grether mentioned that Dr. Paul M. Fitts had been in charge of much of the work, and that various other members of the staff at the Aero Medical Laboratory had contributed greatly to the research summarized by the movie.

The movie was technically very well done and served to dramatize the data obtained in the Aero Medical Laboratory studies.

Discussion of
Factors Influencing Visibility at High Altitudes

H. Richard Blackwell
Vision Committee Secretariat

(Editorial note: Dr. Blackwell began by explaining the purpose behind the discussion of factors influencing visibility at high altitudes. He stated that a request had been received by the Vision Committee Secretariat from the Air Force for the Vision Committee to consider factors influencing visibility at high altitudes in order to prepare a summary of the knowledge now available for transmittal to the Air Force. The problem concerned particularly the visibility of high-speed objects at high altitudes and the primary interest was in the visual detection of aircraft from aircraft. A secondary question was the recognition of changes in velocity of objects traveling at high altitudes.)

The problem of visibility at high altitude may be broken down into two problems, the problem of the specification of the stimulus reaching the observer and the problem of the sensory discrimination of the observer. Specification of the stimulus involves information concerning the brightness of the sky, the illumination of objects from the sky and from the sun, and the reflectance of the object, both diffuse and specular, and the attenuation of brightness contrast by the atmosphere. In addition, the size and speed of the object must be specified. Sensory discrimination involves the detection of the presence of a stimulus and, in some special cases, the detection of change in velocity.

## SKY BRIGHTNESS AND ILLUMINATION

The brightness and illumination of the sky have been the subject of considerable empirial study. For example, Dorno and also Kimble have reported extensive measurements of the brightness of various portions of the daytime sky as seen by an observer stationed on the surface of the earth. Such variables as the altitude and azimuth of the sun, latitude, atmospheric condition and cloudiness have been studied separately. Data on the daytime sky and nighttime sky as seen from the surface of the earth have more recently been reported by Hulburt and Tousey. Extensive empirical studies of the illumination incident on the earth's surface have been made by Comdr. Dayton R.E. Brown. Such variables as the altitude and azimuth of the sun, the orientation of the receiving surface, the latitude, and the atmospheric conditions have been studied. These data have been summarized by Comdr. Brown and a computer designed and constructed which permits computation of the illumination on the surface of the earth as a function of the indicated variables. Jones and Condit have also recently reported a survey of the extensive literature of illumination measurements upon the earth's surface. The average curve adopted by Jones and Condit is in very good agreement with the curve adopted by Comdr. Brown over the range of values employed by Jones and Condit. The data provided by Comdr. Brown extend beyond the Jones and Condit data in the direction of lower levels of illumination which occur during and following twilight.

In addition to the empirical studies which have been numerous, there has been considerable theoretical analysis of the problem of sky brightness and illumination. The most relevant theoretical treatment is that reported by Tousey and Hulburt. The theory of Tousey and Hulburt may be called a theory of molecular scattering. These authors begin by considering the absorption of ozone as though the ozone occured in a separate layer located above the upper atmosphere. The theory is based upon the Rayleigh equations which describe the primary scattering of light by molecules. Tousey and Hulburt have incorporated into the equations, however, a correction for what is called "the polarization defect." This effect results from the fact that the light which is scattered is not all polarized as it should be according to the

Rayleigh theory. In addition, Tousey and Hulburt have introduced an emperical correction into the Rayleigh equations to correct for the apparent excess of molecules found in the air at high altitudes. The empirical correction was based upon measurements of sky brightness made at high altitudes by these authors.

In addition to primary scattering, it is necessary also to consider multiple scattering. Multiple scattering includes both the secondary scattering of light and also reflection of light from the earth's surface. The theory of multiple scattering employed by Tousey and Hulburt assumes that both the upper and lower hemispheres of light are uniform. The hemispheres do not contain the same amount of light, however.

The theory of both primary and multiple scattering is treated as though light were of "average" wavelength. Such a technique approaches the result obtained if the effect of each wavelength is considered separately, and the integrated effect of all wavelengths computed.

The Tousey and Hulburt theory can predict the brightness of the sky due to molecular scattering at various altitudes above the earth's surface. It can also predict the solar illumination at any altitude. Solar illumination is predicted by establishing a standard value of solar illumination at the upper limit of the earth's atmosphere and then reducing this amount of illumination by absorption and molecular scattering. It is also possible to predict the illumination from the sky by means of the theory. Scattered light illumination may be computed directly once the brightness of the sky is known. Since the brightness of the sky is nonuniform, approximation methods are necessary in this case.

The molecular scattering theory as employed by Tousey and Hulburt is an approximation for the following reasons: first, the use of an "average" wavelength approximates the effect to be expected with light of mixed wavelengths. The assumption of a reflectance factor of the earth is an approximation only, since the reflectance of the earth depends upon the time of the year, terrain, etc. Furthermore, the assumption of a uniform hemisphere of light must be considered as an approximation to the nonuniform hemispheres which the theory predicts. Tousey and Hulburt have considered the significance of these various approximations and feel that they do not introduce very considerable error into values predicted by the theory. The most serious approximation arises from the omission of allowances for absorption and scattering by particles other than air molecules. Particularly at low altitudes, where there is considerable dust and water droplets in the atmosphere, these effects may be of great significance and prediction based upon theory which ignores their effects will be in considerable error.

We might conclude that the molecular scattering theory provides good estimates of some qualities and poor estimates of other qualities. The sky brightness viewed from below may be considered to be well estimated by the molecular theory. Non-molecular scatter is relatively absent if the observer is stationed at a reasonably high altitude. Furthermore, the assumption of uniform hemispheres of light is not very bad in this case, since the brightness of the sky is mostly determined by primary scattering. Any approximation in the calculation of multiple scattering is, therefore, of minor significance. The molecular scattering theory provides us with only a poor estimate of sky brightness as viewed from above, since non-molecular scattering will be of particular significance in this case. The theory provides us with a good estimate of illumination on an object viewed from above. The estimate is good because calculations of the solar illumination are relatively certain, and, in this case, the illumination of the object is nearly entirely due to solar illumination. If, for example, one computes the solar illumination and the illumination produced by light scattering from the sky, it may be shown that at altitudes above 10,000 feet the solar illumination provides at least 90% of the total

illumination. For this reason, uncertainties in the brightness of the sky will be of minimum significance. The theory provides us with only a poor estimate of the illumination of objects viewed from below, since, in this case, solar illumination is absent. Illumination from the sky will be poorly estimated because of the uncertainties concerning the brightness of the sky in the direction of the earth's surface.

Unfortunately, the predictions made from the molecular scattering theory are thus not entirely good in the case of objects viewed either from below or from above. If one views objects from above, the illumination on the object is well predicted, but the brightness of the sky is poorly predicted. If, on the other hand, one views an object from below, the brightness of the sky is well predicted, but the illumination on the object is poorly predicted. It would appear, therefore, that, if the visibility of objects seen from high altitudes is important, it will be necessary to attempt to estimate the degree at which the molecular scattering theory is inadequate. Principally, it would appear that empirical studies are needed of the brightness of the sky viewed from above; that is, the brightness of the sky in the direction of the earth as seen from high altitudes. In addition, empirical studies are needed to determine the degree to which the illumination scattered from the sky departs from theory. Departures from theory will be particularly marked in the case of illumination coming up from the earth's surface, but there may also be departures from theory in the case of illumination scattered down from above.

Let us turn now to the question of the prediction of sensory discrimination in the case of visibility at high altitudes. Considerable knowledge is available, particularly from the Tiffany Foundation studies, from which to predict the range at which stationary objects of uniform brightness may be seen against a uniformly bright background. These data are believed to be of very limited value for the purposes of predicting the visibility of rapidly moving objects, seen at high altitudes. In the first place, when the observer and the target are at approximately the same altitude, the target will be non-uniformly bright due to a shadowing effect, and the sky against which the object is seen will also be non-uniformly bright. Systematic investigation has not been made of the degree to which such non-uniformity of brightness of target and background will influence the range at which the objects may be seen.

A factor of probably far greater significance, however, is the factor of the speed of objects which will normally be seen at high altitudes. Study of the visual thresholds for high speed objects has been restricted to what has been called visual acuity. It seems possible that the detection threshold for rapidly moving objects may be considerably different from the acuity threshold. It is also expected that the detection threshold of high speed objects will be much different from the expectations based upon extrapolation of the data obtained with stationary objects. It seems to the speaker entirely possible, for example, that a rapidly moving object will be more visible than one would expect on the basis of a summation of the probabilities of detection of the object as seen at each of a number of positions, each for a restricted time.

There is the further question of the degree to which specular reflections from objects at high altitudes may serve as cues for detection. The high polish of the surface of some targets at high altitudes makes it possible that they will be seen by specular reflectance of the sun's image. Because of the sporadic nature of the appearance of specular images, however, our present knowledge of stationary objects would give us very little indication of the visibility of such specular "flashes."

A further aspect of sensory discrimination of interest appears to be the ability

of the eye to detect a change in velocity of objects. There is a little information in this subject. Hicks, in England, has recently conducted very preliminary studies, which gives us some idea of the magnitude of the effect. Hicks finds that a 12% change in velocity will be discriminated under certain circumstances.

DISCUSSION:

Dr. Hulburt commented that it seemed to him that measurements of sky brightness looking down at various parts of the sky with various angles of the sun were very much needed. He also indicated that, in his opinion, the visibility of rapidly moving objects was the most difficult problem, and that undoubtedly a lot of work would have to be done before sense could be made of it.

Dr. Grether commented that, from the operator's point of view, it has been found that the problems of visibility at high altitudes are greater than they are on the ground. This is particularly true when it comes to detecting the presence of other aircraft, since often other aircraft are seen from below as dark silhouettes against a dark sky. Dr. Grether stated that pilots also indicate that their judgment of distances of other objects at high altitudes is very poor. A further problem concerns the visibility of objects within the cockpit because of the increased contrast of cockpit shadows at high altitudes.

Dr. Gibson asked if anyone has a theory for the discrimination of objects which are rapidly moving. He asked what the definition of the stimulus would be under such circumstances. Dr. Gibson expressed his belief that we must free ourselves of the notion that we must see an object in order to see movement of an object.

Dr. Blackwell expressed his agreement with this latter point. He stated it seemed to him that a moving stimulus might be detected better than would be predicted on the basis of extrapolation of the static thresholds because of the uniqueness of the spatial pattern of cortical excitation corresponding to a moving object.

Dr. Duntley stated that he had an experiment to suggest in connection with the problem of visibility at high altitudes. He stated that one of the crucial items of data necessary for predicting visibility is the inherent contrast of the target. At high altitudes, the inherent contrast of the target is an exceedingly difficult thing to predict. In order to obtain data on the inherent contrast of objects, Dr. Duntley proposed that photographs be taken of objects at high altitudes. Such photographs could be taken by arranging to have two aircraft aloft, one of which would be photographed from the second from every attitude at one altitude. Such data would give a feeling for the problem. Dr. Duntley stated that the change from matte paints to shiny surfaces has greatly complicated the problems of making such measurements. When aircraft were painted with diffusely reflecting paint, it was a relatively simple matter to photograph one aircraft from a second and to utilize the photographs to compute the illumination on the surfaces of the aircraft. Obviously, with glossy surfaces, this simple procedure is no longer possible.

Dr. Blackwell remarked that one of the attractive features of the problem of visibility at high altitudes is that the atmospheric attenuation is constant from day to day so that measurements made on a particular day possess greater generality than is true of measurements made at the earth's surface.

Dr. Hulburt commented that, in his opinion, Dr. Duntley's suggestion was so good that he would throw away the theory and begin with photographs of the sort proposed.

Dr. Grether expressed doubt that it will be possible to predict the visibility of objects from threshold data. He emphasized the fact that there is a tremendous range of sky which must be scanned, and that consequently objects often come surprisingly close before they are detected, because the observer is looking in the wrong direction.

Dr. Blackwell commented that the techniques developed by Dr. Lamar of the Operations Evaluation Group of the Navy were intended to apply the mathematics of game theory to the problem of visibility of an object which might appear anywhere in a wide expanse of sky. It is, however, necessary to have threshold data representing the sensitivity of the eye at various positions of the visual field in order for the calculation of the probability of detecting an object to be made. Dr. Blackwell stated his opinion that a restriction in the applicability of the Operations Evaluation Group method arises from the fact that it was assumed that one could extrapolate data obtained on stationary targets to the case at which objects are rapidly moving. If it is true that rapidly moving objects are detected better than would be predicted on the basis of static considerations, then the Operations Evaluation Group method must be revised somewhat.

Dr. Tousey reported that he and Dr. Hulburt were surprised to find that stars may be seen in the daytime provided one looks directly at them, but as soon as the line of sight is directed only a small distance away from the stars, they can no longer be seen. Dr. Tousey expressed his belief that the non-uniformity of sensitivity across the fovea for point sources is a more important phase of the problem than whether the target is moving or not.

Dr. Blackwell reported recent results obtained with point sources showing that the threshold does indeed change as much as tenfold across the central fovea. The change occurs with monochromatic points as well as with white points. It appears that there is a marked change in sensitivity within a range of ten minutes from the center of the fovea.

Commander Brown asked whether the Vision Committee was going to work further on the problem of visibility of objects at high altitudes.

Colonel Byrnes reported that the Executive Council had appointed Dr. Blackwell to be chairman of a working group on this subject.

# THE VISABILITY OF SUBMERGED OBJECTS

## I PHYSICAL FACTORS

Seibert Q. Duntley

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### I Introduction

During the spring of 1948, the Vision Committee received a request from Buships and C.N.O. for information concerning the visibility of submerged submarines. After due deliberation by the Subcommittee on Visibility & Atmospheric Optics, the Vision Committee recommended to the Office of Naval Research that a research project be initiated to explore the physical and visual factors which limit the detectibility of fully submerged submarines. (See Minutes of 21st meeting, pp. 81-88) This paper is the first part of the final report of the resulting research project.

The Minutes of the 23rd meeting of the Committee contain an interim report which described exploratory studies of some of the physical factors that influence the visibility of submerged objects. (Min., 23rd meeting, pp. 123) That report was concerned primarily with the optical principles that govern the transmission of an image through water, and it set forth the experimental finding that the apparent contrast of any submerged object is exponentially attenuated with distance along any path of sight. Continued research on this topic has yielded further information, but renewed discussion of it will be postponed until the second portion of this report.

The interim report at the 23rd meeting also described photometric measurements of the apparent contrast of a submerged object as viewed both from above the water surface and from beneath the water surface. (See Figures 1 & 2, pp 126, 23rd Meeting) It was pointed out, in Figure 2 of that paper, that these contrast data could be expressed as a contrast reduction factor which varies regularly with the state of the sea and with the altitude of the sun. The precise nature of the contrast reduction equation was not known, nor were all of the physical factors apparent. It was stated, however, that a major goal of further research in this field was to be the identification of the pertinent parameters, the development of experimental techniques for their measurement at sea, and the discovery of the law of contrast reduction. All three of these goals have been reached, and it now appears possible to predict the apparent contrast of a fully submerged submarine as seen by an aerial observer under virtually any circumstances.

The general nature of the problem is illustrated in Figure 1, in which a submerged object of reflectance R forms a contrast $C_o$ with a water background of reflectance $R_w$. The magnitude of this contrast depends upon the altitude of the sun and the relative amount of sunlight in the daylight impinging on the surface of the water. Known optical principles can be used to predict the apparent contrast seen by the observer whenever the water surface is perfectly calm. If, however, the water surface is roughened by wind, additional information and new optical principles must be employed in the computation. The manner in which a wind-roughened water surface reduces the apparent contrast of submerged objects will be discussed in the following paragraphs.

### 2. The Sea-state Meter

The amplitude of water waves is of little concern optically; it is the slope of the water surface which determines the refractive and reflective effects. An electrical instrument for measuring wave slopes has been devised and used in

experiments both at Diamond Island and at sea. The instrument, designed to indicate the conventional (amplitude) sea-state as well as the water slope, has been called a "sea-state meter." It is arranged to record the difference in water height at two closely adjacent points. Two pairs of stainless steel wires are mounted as shown in Figure 2 and powered by the same 2000 cycle alternator. After detection, the signals are subtracted, thus producing a voltage proportional to the water slope. After suitable further amplication, the signal is recorded by a direc-writing oscillograph (Brush, BL 202). The signal is also sent through an electronic computer which performs a statistical analysis of the data.

The apparatus shown in Figure 2 is used in duplicate so that orthogonal components of wave slope can be recorded simultaneously. Provision has also been made for the simultaneous recording of wave amplitude, and a typical record is shown in Figure 3. Slope cannot be obtained by differentiation of the amplitude record with respect to time, partly because the slope is a vector quantity and partly because of dispersion. It will be noticed in Figure 3 that the slope components exhibit a higher frequency than the amplitude record, but that neither of the slope records can be obtained by differentiation of the amplitude record.

After numerous water wave records had been studied, it was concluded that the frequency of occurrence of a given slope always closely approximates a normal distribution. This is illustrated by Figure 4, which represents the first data obtained by the sea-state meter (November 6, 1949). A slight asymmetry in the direction of the wind can be seen by comparing the dotted (symmetrical) curve with the solid (experimental) curve on the left side of the distribution. This indicates a slight preponderance of steeper slopes in the direction away from the wind. These data were taken with electrode spacing of approximately one inch between wire pairs. More recent data, taken with an effective electrode spacing of one tenth of an inch, shows almost no "downwind" effect. This means that the very tiny capillary wavelets, having wavelengths less than an inch, contribute so many randomly distributed steep slopes that the asymmetry of the large gravity waves becomes negligible in their effect on the distribution of true slopes.

The closeness with which the slope measurements follow a normal distribution can be better judged by plotting on a logarithmic scale the relative number of counts against the square of the slope, as is done in Figure 5. The straight line in this figure represents the equation:

where $h^2 = 19.2$

$$n_\phi / n_0 = e^{-h^2 \tan^2 \phi} \qquad (1)$$

Figure 6 shows simultaneous data from electrodes mounted at right angles to those from which the foregoing data were taken. The straight line on this plot also represents equation (1) with $h^2 = 19.2$. It has been inferred from these plots, and from a large number of similar data, that equation (1) is a satisfactory representation of the probability of the occurrence of a slope component of given magnitude. The optical effects caused by water waves can be described, therefore, in terms of a single constant, $h^2$, which describes the spread of the probability distribution curve. It has been found convenient, however, to use the reciprocal of this quantity for describing the optical state of the sea because the reciprocal of $h^2$ provides a scale of numbers which runs from zero (for perfectly calm water) up to infinity. The symbol S and the definition $S=1000/h^2$ has been adopted for "optical sea-state" and will be used throughout the remainder of this paper. The most commonly observed values of S fall in the range from 10 to 100.

The symmetrical two-dimensional nature of the probability curves just described is illustrated in Figure 7, which is an isometric projection of two identical probability curves at right angles. These curves may be regarded as

traces on a surface of revolution. At any point on this surface, the altitude above the base plane is given by equation (1). The volume of any cylindrical element beneath this surface is a measure of the probability of the occurrence of a slope having magnitude between $\tan\phi - \frac{1}{2}d(\tan\phi)$ and $\tan\phi + \frac{1}{2}d(\tan\phi)$.

The incremental fractional time $d\hat{t}_\phi$ during which slopes of this magnitude occur is then:

$$d\hat{t}_\phi = 2\pi \tan\phi \, C e^{-h^2 \tan^2\phi} \, d(\tan\phi) \qquad (2)$$

Equation (2) will be used as the basis for deriving an expression for the time-averaged apparent contrast $\overline{C}$ of submerged objects. In the case of an aerial observer too high to resolve individual wave facets, the observed (space-averaged) apparent contrast is equal to the time-averaged apparent contrast $\overline{C}$.

## 3. Contrast Reduction by Refraction

Part of the reduction in contrast at the water surface is caused by time-varying refraction. An observer looking straight down at a wind-roughened water surface receives light from the depths directly beneath him only part of the time, because of the rapid and random changes in wave slope. His path of sight, deviated by refraction, sweeps out a solid cone having a half apex angle $\psi_M = \cos^{-1} 3/4 = 41.4$ degrees, as shown in Figure 8.

Let B represent the apparent luminance of the under-water field of view in Figure 8. The time-averaged upwelling apparent luminance $\overline{B}_u$ is then:

$$\overline{B}_u = \int_0^{\psi_M} B_\psi \, d\hat{t}_\phi \qquad (3)$$

In the special but common case of a submerged target of angular subtense $\psi_T$ and apparent luminance $B_T$ seen against a uniformly luminous background of luminance $B_w$, equation (3) becomes:

$$\overline{B}_u = \int_0^{\psi_T} B_T \, d\hat{t}_\phi + \int_{\psi_T}^{\psi_M} B_W \, d\hat{t}_\phi \qquad (4)$$

and the time-averaged apparent luminance of the target $\overline{B}_T$ is:

$$\overline{B}_T = B_T \left(1 - e^{-1000(\tan^2\phi_T)/S}\right) + B_W e^{-1000(\tan^2\phi_T)/S} \qquad (5)$$

Defining calm water apparent contrast C and time-averaged apparent contrast $\overline{C}$ as:

$$C = \frac{B_T - B_W}{B_W} \qquad (6)$$

and

$$\overline{C} = \frac{\overline{B}_T - B_W}{B_W} \qquad (7)$$

equations (5), (6), and (7) can be combined as follows:

$$\overline{C} = C\left(1 - e^{-1000(\tan^2\phi_T)/S}\right) \qquad (8)$$

Thus, the time-averaged apparent contrast of a submerged object is seen to depend upon the optical sea-state S and the angle subtended by the target at the surface of the water. For example, in the case of a target for which $\tan\phi_t = 0.1$ ($\psi_T = 4.3$ degrees) and barely ruffled water (S = 10), it will be seen from equation (8) that $\overline{C} = 0.632C$, whereas in water roughened by a 40 knot wind (S = 100) the time-averaged apparent contrast of the same target will be reduced to 0.095 of its calm-water value.

## 4. Sky Reflection

The surface of the sea acts as a moving mirror which always reflects light from some portion of the sky to the eye of an aerial observer. This reflected sky light further reduces the time-averaged apparent contrast of any submerged object. Equation (2) can be used as the basis for computing the time-averaged apparent luminance of the water surface $\bar{B}_r$. Referring to the geometry of Figure 9, it will be seen that

$$\bar{B}_r = \int_0^{\pi/4} r_\phi B_\theta \, d\hat{t}_\phi \qquad (9)$$

where $r_\phi$ is the reflectance of the water surface for light incident at an angle $\phi$ with the normal. Because of the complex nature of the luminance in the sky, equation (9) must be made two-dimentional.

The collection of sufficient data to permit the evaluation of the integral in equation (9) is impracticable. Fortunately, the following simple experimental approach can be made. Let equation (9) be modified as follows:

$$\bar{B}_r = \int_0^{\pi/4} r_\phi B_\theta \, d\hat{t}_\phi = s\, r_0 B_0 \qquad (10)$$

where $r_0 B_0$ is the reflected luminance of the zenith sky and s is a "sky factor" defined by equation (10). It will be noted that s depends not only on the state of the sky as specified, by $B_\theta$, but also on the state of the sea as specified by $d\hat{t}_\phi$. An experimental technique for the evaluation of s has been devised on the basis of the following reasoning:

An observer looking downward at a calm surface sees a reflected image of the zenith sky. Whenever the action of wind converts the water into a moving mirror, the observer's path of sight sweeps the sky in exactly the same manner as would a beam of light projected downward from the position of the observer and reflected by the moving water surface. This is illustrated by Figure (10). The distribution of time-averaged intensity of the water surface at point A has conical symmetry because of the symmetry of slopes as represented by Figure 7. The time-averaged flux $\overline{dF}_\theta$ within the conical solid angle dw illustrated in Figure 10 is:

$$\overline{dF_\theta} = r_\phi E A \, d\hat{t}_\phi \qquad (11)$$

and the solid angle

$$d\omega = 2\pi \sin\theta \, d\theta \qquad (12)$$

The time-averaged intensity $\bar{I}_\theta$ is then:

$$\bar{I}_\theta = \frac{\overline{dF_\theta}}{d\omega} = \frac{r_\phi E A C e^{-1000(\tan^2\phi)/S}}{2\pi(1+\cos\theta)^2} \qquad (13)$$

When $\theta = 0$

$$\bar{I}_0 = \frac{r_0 E A C}{8\pi} \qquad (14)$$

Thus

$$\frac{\bar{I}_\theta}{\bar{I}_0} = \frac{4 r_\phi e^{-1000(\tan^2\phi)/S}}{r_0 (1+\cos\theta)^2} \qquad (15)$$

Equation (15) represents the time-averaged distribution of intensity in the water surface at point A when illuminated by a beam incident vertically downward. Let a photoelectric receptor be given a distribution of zonal sensitivity specified by equation (15). The response of this "sky collector" will then be

proportional to the luminance of the entire sky (including the sun) weighted in accordance with the fractional time which the observer in Figure 9 sees a given portion of the sky. If the sky-collector is subsequently presented to a uniform (artificial) sky having the luminance of the real sky at the zenith, the ratio of its two readings will be the sky factor s in equation (10).

Such a sky-collector has been built and is illustrated in Figure 11. A matte-surfaced translucent sphere is secured to the top of a pipe having a photoelectric cell ( not shown) fastened to its lower end. This spherical collector is mounted at the center of a hollow metal sphere containing curved meridinal slots so shaped that the collector is given the zonal sensitivity specified by equation (15). The outer sphere is rotated rapidly during measurement so that the sky is uniformly weighted in all azimuths.

The slots in the sky-collector sphere can be cut for only a single optical sea-state S, but it has been found that if this is done for S = 100 (rough water) the characteristics specified by equation (15) for calmer sea-states can be closely approximated by lowering the spherical collector relative to the outer sphere as shown in Figure 11.

Thus, the procedure for determining the sky factor s involves (1) the measurement of the optical sea-state S by means of the sea-state meter, (2) adjusting the sky collector to the appropriate value of S and noting its reading, and (3) covering the sky collector with an artificial sky of uniform luminance equal to that of the zenith $B_o$ and noting a second reading. The ratio of the first and second sky collector readings is the sky factor s.

The second portion of this paper will set forth the derivation of the complete equation for the apparent contrast of a submerged object, including the surface effects just described, and such other contrast reducing mechanisms as scattering and absorption of light within the water.

The resulting equation will be shown to be:

$$C = C_o \left(1 + e^{-1000 (\tan^2 \phi_T)/S}\right)\left(1 + \frac{s_\alpha r_\alpha b_K}{b_{\omega_1}}\right)^{-1}\left(e^{-3.912 \, d \, v_\alpha^{-1} \sec \alpha'}\right) \qquad (16)$$

The meaning of equation (16) and its application to the prediction of the visibility of submerged submarines will be the subject of the second part of this paper.

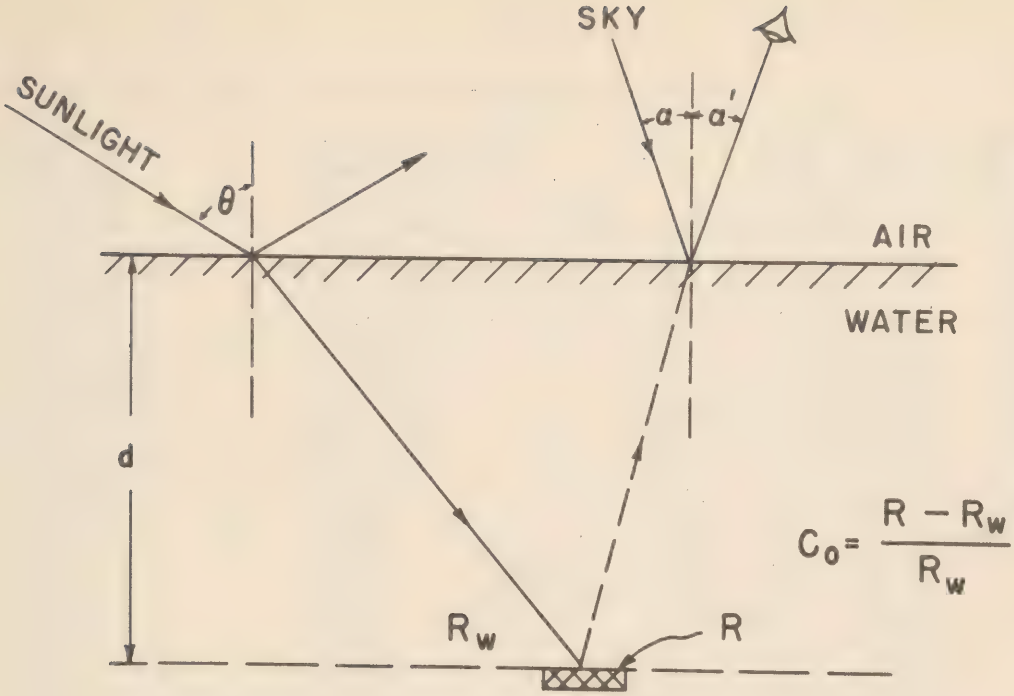



Figure 1

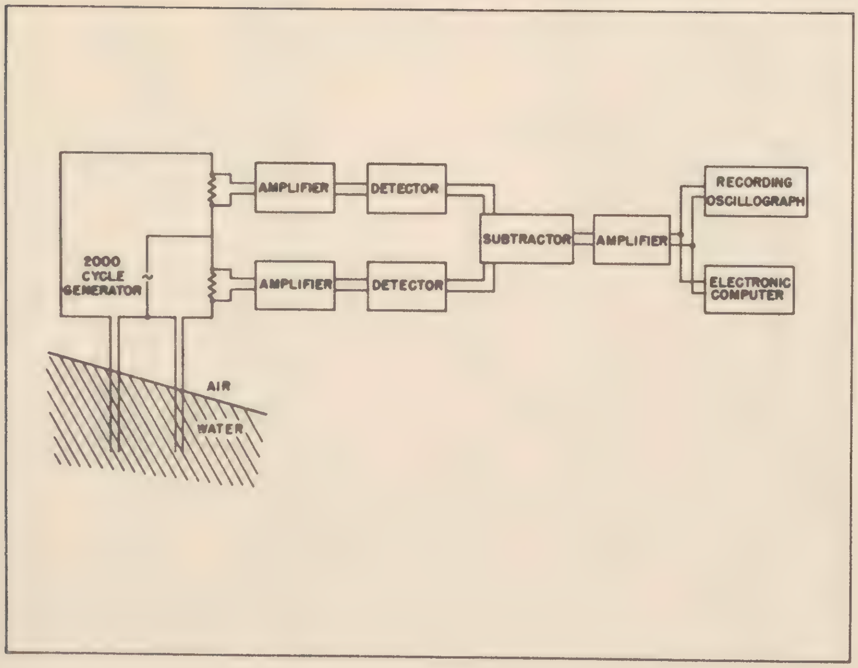
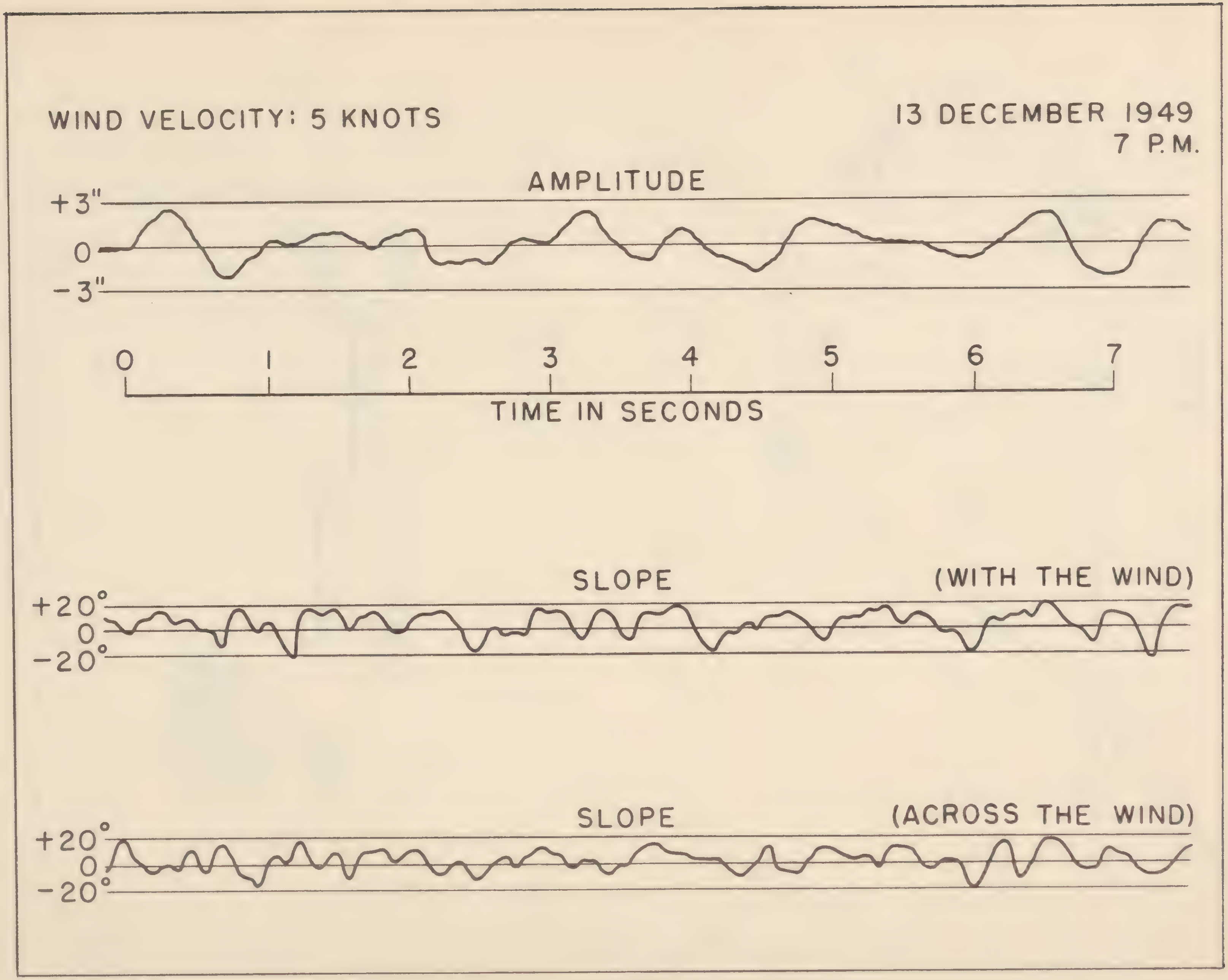



Figure 2



WIND VELOCITY: 5 KNOTS
13 DECEMBER 1949
7 P.M.
AMPLITUDE
+3"
0
-3"
0
1
2
3
4
5
6
7
TIME IN SECONDS
SLOPE
(WITH THE WIND)
+20°
0
-20°
SLOPE
(ACROSS THE WIND)
+20°
0
-20°


Figure 3

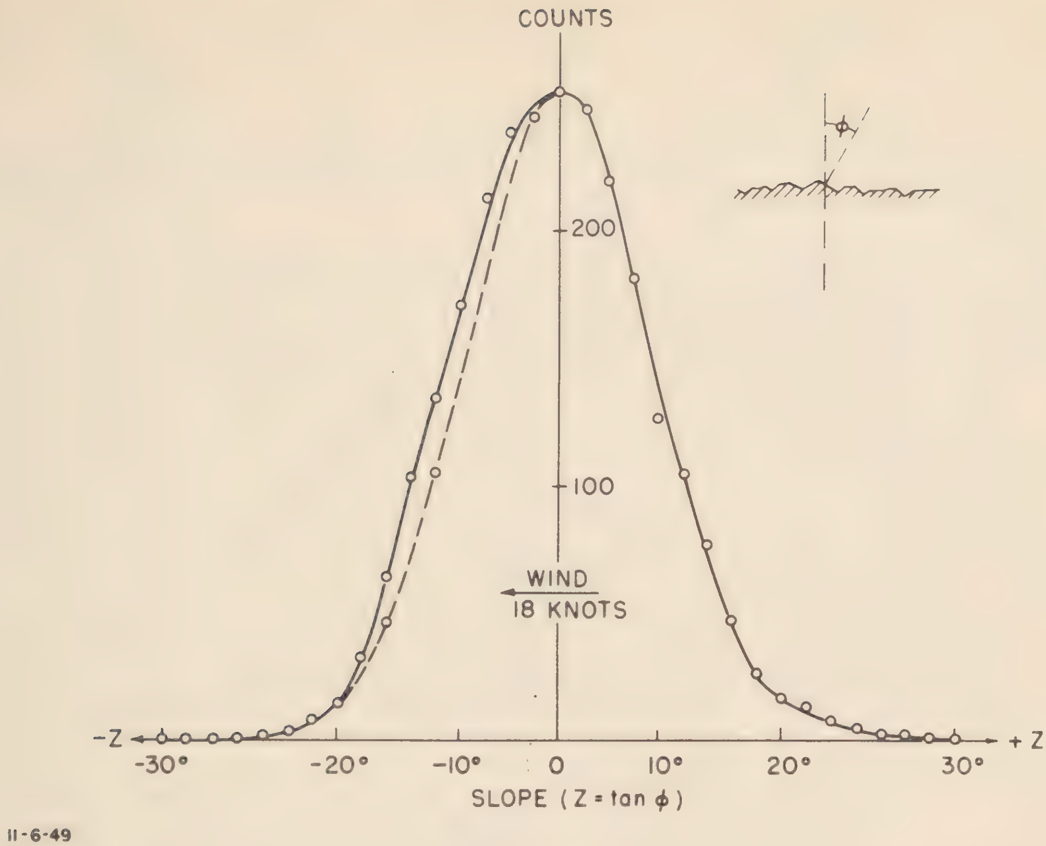



Figure 4

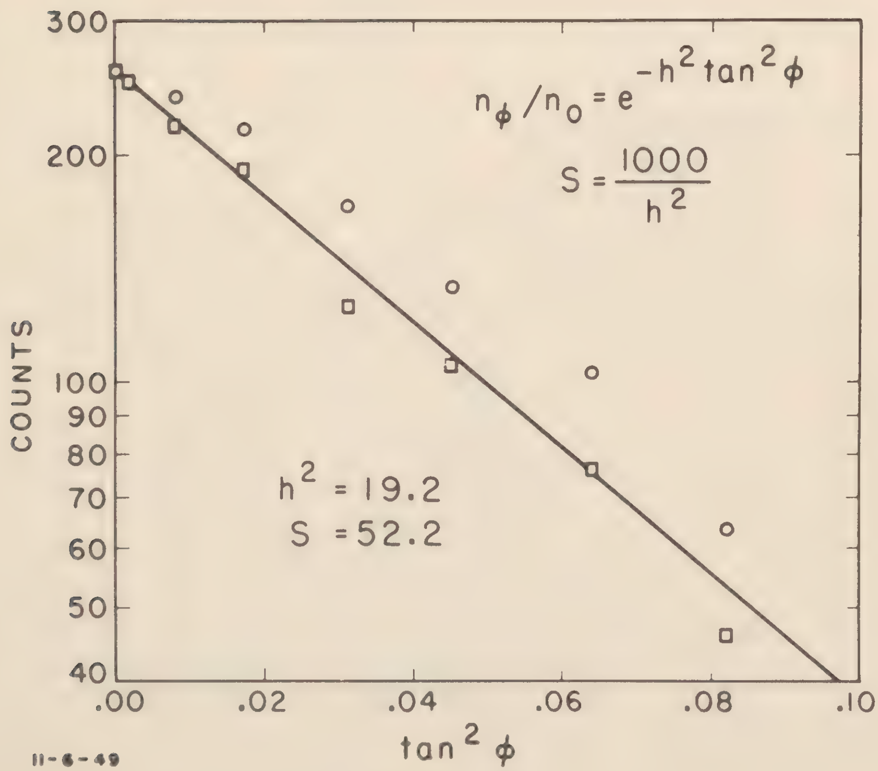



Figure 5

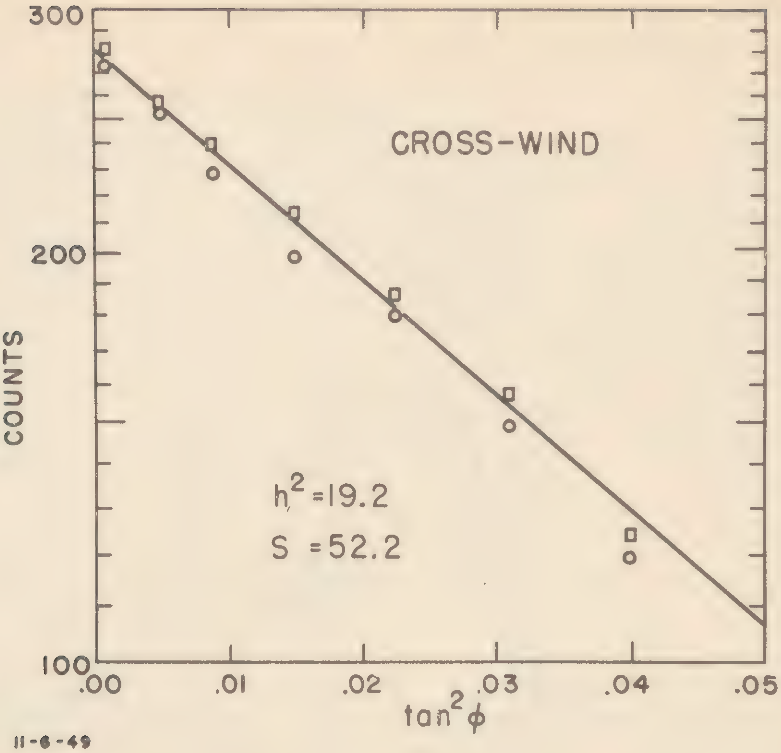



Figure 6

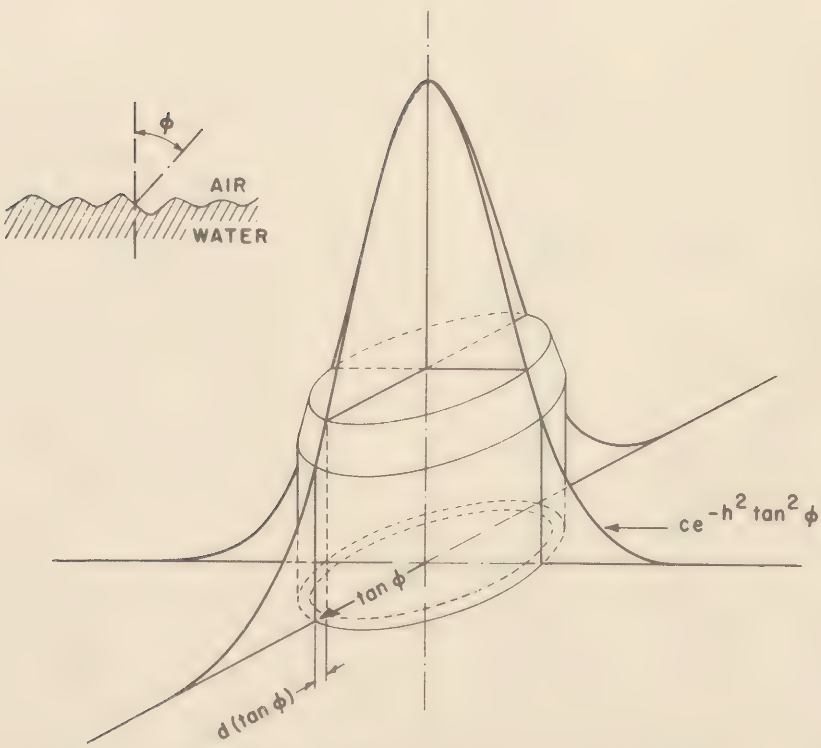



Figure 7

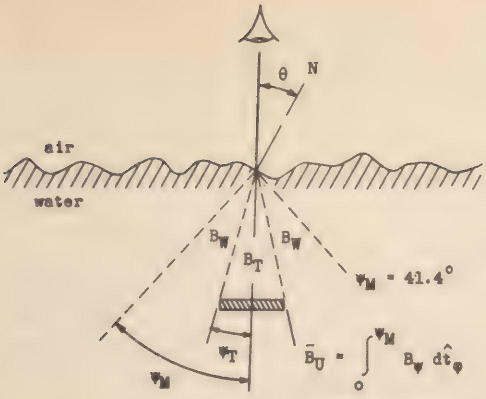



Figure 8

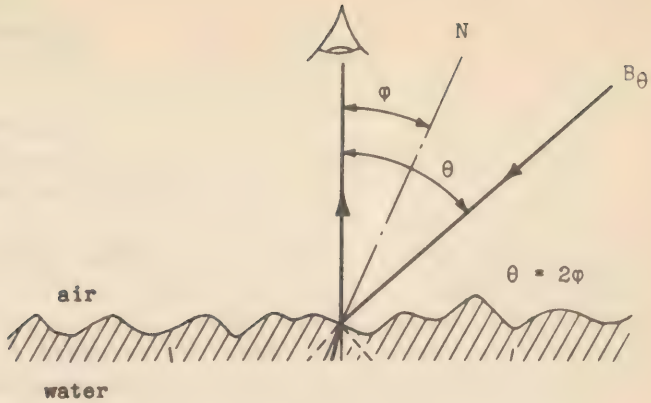



Figure 9

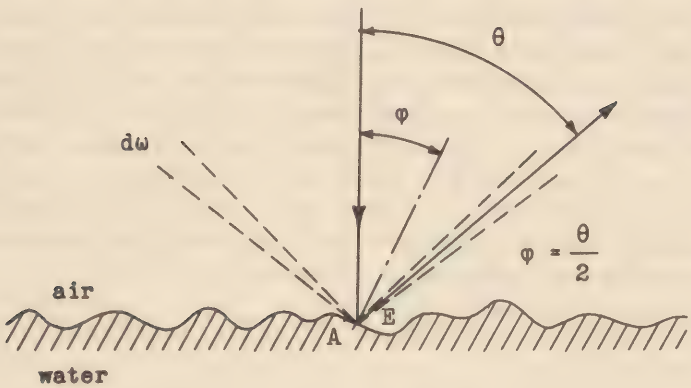



Figure 10

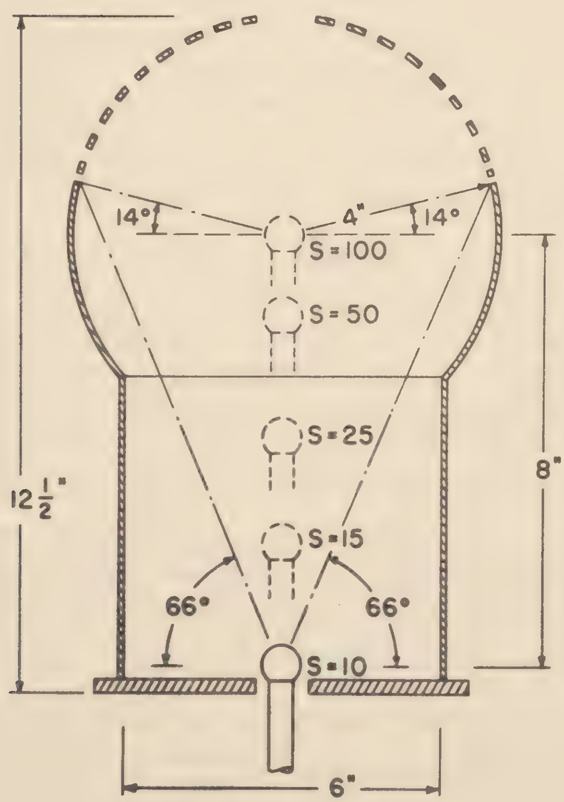



Figure 11

Announcement re
Awarding of the Adolph Lomb Medal
to Dr. H. Richard Blackwell

Stanley S. Ballard

Dr. Stanley S. Ballard, who is an officer of the Optical Society of America, announced that the Adolph Lomb Medal of the Society had been awarded to Dr. H. Richard Blackwell at the recent annual meeting of the Society which was held in Cleveland, Ohio, on October 26-28. Dr. Ballard stated that he realized that a number of members of the Vision Committee had attended this meeting, but he wanted to make sure that all were aware of this honor which has come to one of our colleagues. The Adolph Lomb medal is conferred biennially upon a candidate who is under 30 years of age and has produced outstanding work in the field of optics. The citation, which was read by Dr. Deane B. Judd, in the absence of the chairman of the committee (Dr. H. K. Hartline), stated among other things that "Dr. Blackwell has done more than anyone else to supply a quantitative basis for the visibility of objects and lights. His use of the multiple-time-choice method of determining visual thresholds combined with machine methods of recording and processing these data has been extremely successful."

# Respired Oxygen and Visual Photosensitization

(Abstract)

W.J. Crozier.

1. Experiments were undertaken to test the deduction, derived from the spectral distribution of the parameters of seeing-frequency functions (Proc. AF-NRC Vision Comm., May 1950, p. 25; J. Gen. Physiol., 34, 87, 1950), that at the fovea there appears to be involved in visual excitation a complex of photosensitization processes in which specific cytochrome-system components may serve as sensitizers.

2. The fact of the occurrance of photosensitization was independently established through an examination of the $\Delta I$ problem by a new technic, involving the determination of seeing-frequency functions with a small test image flashed briefly on a large fixed field of controlled intensity (which may be = 0). The "absolute" intensity threshold at full dark-adaptation does not give a measure of maximum visual sensitivity. Recognition of this fact has a number of interesting consequences. The treatment of this situation, in relation to $\lambda$, and including the very important heterochromatic case (in which $I_1$ is of $\lambda_a$, $I_2$ of $\lambda_b$) will be discussed elsewhere in some detail.

3. For a test of the possible involvement of cytochrome-system components as photosensitizers (at the fovea), resort was had to the known lability of the equilibria between the concentrations of the reduced and the oxidized forms of cyt.-c and cyt.-a, while cytochrome-c reductase (a flavin compound) does not react with $O_2$. The experiments therefore consisted in the establishment of (uni-ocular) see-frequency functions, at a large number of $\lambda$'s with the observer breathing (at sea level pressure) (i) 10 per cent. $O_2$, (ii) 21 per cent. $O_2$, (iii) '100' per cent. $O_2$. The expectation was that the 'orthodox' finding of an increase in visual sensitivity with increased partial pressure of respired $O_2$ might be defeated in a mid-spectral range. This is the range ($\lambda 550$ - $\lambda 605$) in which peaks of photosensitization had been tentatively correlated with the absorption maxima of reduced cyt.-c and of reduced cyt.-a. This expectation was thoroughly substantiated. In this range, median threshold intensities are substantially lowered by the respiration of $O_2$ - $N_2$ mixtures (containing appropriate tensions of $CO_2$ and of water-vapour) containing 8 - 10 per cent. $O_2$. This is consistent with the deduction outlined in § 1; no alternative mechanism is apparent.

4. The detailed interpretation of the data forces recognition of the fact that $O_2$ in respired air has 2 kinds of effect on visual threshold experience. The first effect is on retinal performance; the second effect is unquestionably of central nervous locus. The evidence is of several sorts: (i) with high-$O_2$ intake, over most of the spectrum the seeing-frequency for proper colour is enhanced although the acting intensities are lowered: (ii) the $O_2$ effect on median binocular thresholds is greater than on either of the uniocular performance data involved.

5. The exposure-time used for the greater part of these observations was 0.051 sec. The precise order of the phenomena is quantitatively a function of the exposure-time. At brief exposures (0.001 sec.) the role of $O_2$ is less pronounced. For very brief exposures (e.g. 0.00004 sec.) the nature of the problem changes radically.

6. The multi-variate character of foveal excitability requires extension of these observations in several directions. At the moment, the facts here qualitatively and in part summarized are consistent with recent deductions. The role of image size and of exposure time is of particular moment for further development. Photosensitization is apparent outside the fovea, but in detail the story is quite different.

DISCUSSION:

Dr. Blackwell commented on the potential practical consequences of the photosensitization phonomenon. The results obtained by Dr. Crozier suggest that it would be advantageous to light adapt to a low level of brightness in order to insure optimal performance in the dark. The wavelength effects are particularly striking and offer special possibilities in this direction.

Dr. Blackwell reported a set of measurements he had made in conjunction with the Roscommon visibility tests in which the photosensitization phonomenon failed to appear. Binocular vision was employed utilizing white light for both the background and the test stimuli. The background subtended approximately six degrees, whereas the test stimuli subtended considerably less than one-half minute of arc. Detection thresholds were obtained at total darkness and at several brightness levels from $10^{-4}$ to $10^{-2}$ foot-lamberts. Dr. Blackwell reported a systematic increase in threshold as the brightness was increased from zero which is the result expected on the basis of the old theory of adaptation and equilibrium conditions. Thus, in these results, there was no evidence of photosensitization. One curious result which was obtained, however, was that the threshold decreased at brightness levels of the background less than $10^{-3}$ foot-lamberts, although it had been supposed that there would be no further decrease in threshold below this level, since presumably below $10^{-3}$ foot-lamberts the limiting cone threshold would have been reached. On the contrary it was found that there was at least a tenfold decrease in threshold as the background brightness was reduced below $10^{-3}$ foot-lamberts. Dr. Blackwell emphasized that he did not suggest that photosensitization does not occur under some conditions; he simply wanted to point out that under some conditions at least the effect does not seem to manifest itself.

Dr. Crozier commented that he would expect the effect of photosensitization to depend on the precise experimental conditions, and that, therefore, photosensitization might not always be found.

# Binocular Measurements of Physiological Nystagmus

by

Lorrin A. Riggs, Brown University

## Acknowledgment

These experiments were done in collaboration with Dr. Floyd Ratliff, now at the Department of Biophysics, Johns Hopkins University. The work was done under Contract N7onr-358, Task Order II, Project NR-141-359, between Brown University and the Office of Naval Research (arranged through the Psychophysiology Branch of the Medical Sciences Division).

## Introduction

The present research concerns the relation of movements of the two eyes to visual acuity in general and stereoscopic acuity in particular. Previous research in this laboratory has indicated that a minute tremor exists during steady fixation on a stationary target. The median extent of the tremor is approximately 20 seconds of arc from crest to trough of wave, and the waves are found to range in frequency from about 30 to 90 per second. Horizontal and vertical components of the tremor are quite similar.[1] Acuity for a grating test object is found to bear an inverse relationship to the amount of this tremor.[2]

The immediate problem is to determine whether the two eyes are synchronized with respect to the minute tremor. To explore this problem, it has been necessary to provide each eye with a plane mirror mounted on a carefully fitted and corrected contact lens. Two separate beams of light are provided, such that a beam from each eye is incident upon a constantly moving photographic film. In Figure 1 is a diagram of the basic system of recording. This system was changed by the addition of appropriate fixed mirrors so that records from both eyes could be made simultaneously on the same film. The horizontal component alone was recorded in this way.

## Results

Figures 2, 3 and 4 show sample records exhibiting the typical drifts, jerky motions and minute tremor for each eye of one of the subjects. It may easily be seen that all of the motions except the minute tremor are closely synchronized. The tremor itself, however, is seen to be independent, so that the two eyes are never perfectly coordinated.

Various control experiments have been performed to make sure that the movements recorded are indeed those of the eye and not artifacts resulting from the contact lens or other parts of the apparatus. Figure 5 shows that when the contact lens is mounted on the apparatus itself no unsteadiness appears in the record.

Figure 6a was obtained by the usual means of a plane mirror mounted on a contact lens. Figure 6b shows a similar record obtained under comparable conditions by the use of a mirror of less than one square millimeter mounted directly on the sclera. In this case no contact lens was used. In more recent experiments we have mounted a mirror on a corneal type of contact lens and in some experiments we have added weights to the regular contact lens in order to alter the inertial properties of the attachment to the eye.

A careful consideration of all the records obtained in this wide variety of methods shows that the minute tremor has similar characteristics of amplitude

and frequency in all. It is concluded that any slippage of the contact lens is minor by comparison with the eye movements as recorded. This conclusion is strengthened by the fact that our regular contact lenses are able to follow movements of up to 3 or 4 minutes of arc without distortion when the subject looks from one fixation point to another in rapid succession. With fixation points farther apart, the regular type of contact lens exhibits a slippage to the extent that from 70 to 90% of the eye movement is recorded. For very large excursions the distortion again becomes smaller, presumably owing to the fact that the lens encounters the corneal bulge.

Figures 7 and 8 show a comparison between records obtained by the use of the contact lens and those obtained by a corneal reflection technique similar to that of a commercial ophthalmograph. It is seen that our method is much more sensitive than that of corneal reflection, so that in the latter method the minute tremor is not revealed.

## Discussion

Our conclusion from the above results is that the eyes are never similarly stimulated by a single point in the visual field. Over brief intervals, when no movement is present except for minute tremor, the mean position of a retinal point for the right eye may be identified rather closely with the mean position of a corresponding point for the left eye. The instantaneous separations of the two "corresponding" retinal points, however, must deviate rather widely (i.e., to a median extent of 10 to 20 seconds of arc) from the mean separation. It therefore appears that the notion of anatomical corresponding points on the retina does not hold strictly, but must be modified to include a rather broad range of correspondence.

The above conclusion is seemingly at variance with recent data on stereoscopic acuity which reveal that disparities of about 2 seconds of arc between images for the two eyes can be used as cues for the perception of depth.[3] In other words, the correspondence of image points for the two eyes is much closer than the correspondence of points on the retina. We may perhaps resolve this apparent contradiction by assuming that in stereoscopic vision we somehow integrate in time so that the mean retinal location rather than the instantaneous retinal location is the basis for stereoscopic acuity. Existing data on the subject of exposure time[4] do reveal very much lower acuity for brief flashes than for longer exposures, as would be expected from the above hypothesis. We are obviously in need of specific data relating stereoscopic acuity to exposure time and extent of binocular eye tremor.

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3. Berry, R.N. Quantitative relations among vernier, real depth and stereoscopic depth acuities. J. exp. Psychol., 38, 708-721, 1948.

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DISCUSSION:

Dr. Hulburt asked Dr. Riggs for clarification as to how the placing of a mirror on the exterior of the eye could be used to measure oscillations of the eye.

Dr. Riggs reported that, since the eye is approximately spherical, and rotates approximately about its center, oscillations of the eye result in movement of a mirror placed on a contact lens mounted over the cornea of the eye. It may be shown that a mirror may be employed as an optical lever in such a way that oscillations of the eye result in lateral and vertical displacement of a beam of light reflected from the mirror. Dr. Riggs reported that the precise movement of the mirror may be related to oscillations of the eye by a calibration technique in which the movement of the beam of light reflected from the mirror may be measured for known movements of the eye. This may be accomplished by having the eye move its fixation from one to a second fixation point.

Dr. Sloan asked for clarification of the use of the cornea as a mirror.

Dr. Riggs stated that the optics are quite complicated in the case in which the cornea is employed as a mirror for the measurement of the oscillations of the eye. The complications arise because the cornea has a radius of curvature different from that of the eyeball as a whole. Therefore, the image of a point of light focused by the cornea will be displaced somewhat from where it would be located if the cornea had a radius of curvature equal to that of the eye. If the cornea were perfectly spherical, the image of a point of light would not move at all as the eye oscillates. Dr. Riggs reported that he was surprised with the fineness of the image of a point of light formed as the cornea reflection.

Dr. Grether asked what Dr. Riggs considered the oscillations of the eye to be due to. He asked whether they might be due to the sporadic nature of the innervation of the eye muscles.

Dr. Riggs stated that he believed the tremor of the eye was due to just this kind of mechanism. The speed of the oscillation suggests that they are due to the separate firings of individual muscle fibers.

Dr. Scobee suggested that the validity of this hypothesis could be tested by varying the constant innervation to the eye by introducing prismatic power gradually before one eye. As the innervation increases, according to this theory, the tremors should increase.

Dr. Riggs thanked Dr. Scobee for his excellent suggestion, and stated that he would try it and let him know the results in the near future. Dr. Riggs stated that the only phenomenon of a similar sort which had been encountered was the difference between individuals in the tremor magnitude. Dr. Riggs stated that his own eyes were the most "steady," whereas the eyes of his associate were definitely more "jittery."

Dr. Blackwell suggested that Dr. Riggs might be interested in trying a separate kind of recording technique for the movements of the eye. He reported an attempt made at Michigan to obtain photographs at high-speed of a scleral blood vessel. As the eye oscillates, the blood vessel moves laterally and vertically, although, of course, the movement is very small. An attempt was made to take high magnification stroboscopic photographs in order to determine if eye oscillations could be detected. Professor Edgerton, of Massachusetts Institute of Technology, attempted to take the pictures, but there was insufficient light for sufficiently high magnification to be employed. Following the failure of the high speed

DISCUSSION (cont'd)

photographs, a direct viewing method was employed. A microscope was used to obtain a high magnification view of a scleral blood vessel. It was possible under these conditions to observe single corpuscles proceeding in file through the small blood vessel in the sclera. If the eye oscillated, the corpuscles should appear blurred. In the tests made, the corpuscles did not appear blurred most of the time. In order to permit interpretation of this result to be made, an experiment was conducted to determine the amount of blur which was detectable under similar circumstances. It was determined that approximately 0.25 minutes of blur was detectable. These results seem to indicate, therefore, that the continuous oscillating of the eye could not exceed some 0.25 minutes in amplitude.

Dr. Blackwell suggested that Dr. Riggs might be able to make direct photographic measurements, and stated that such measurements, if they could be made, would represent corroboration of the results obtained with the contact lens technique.

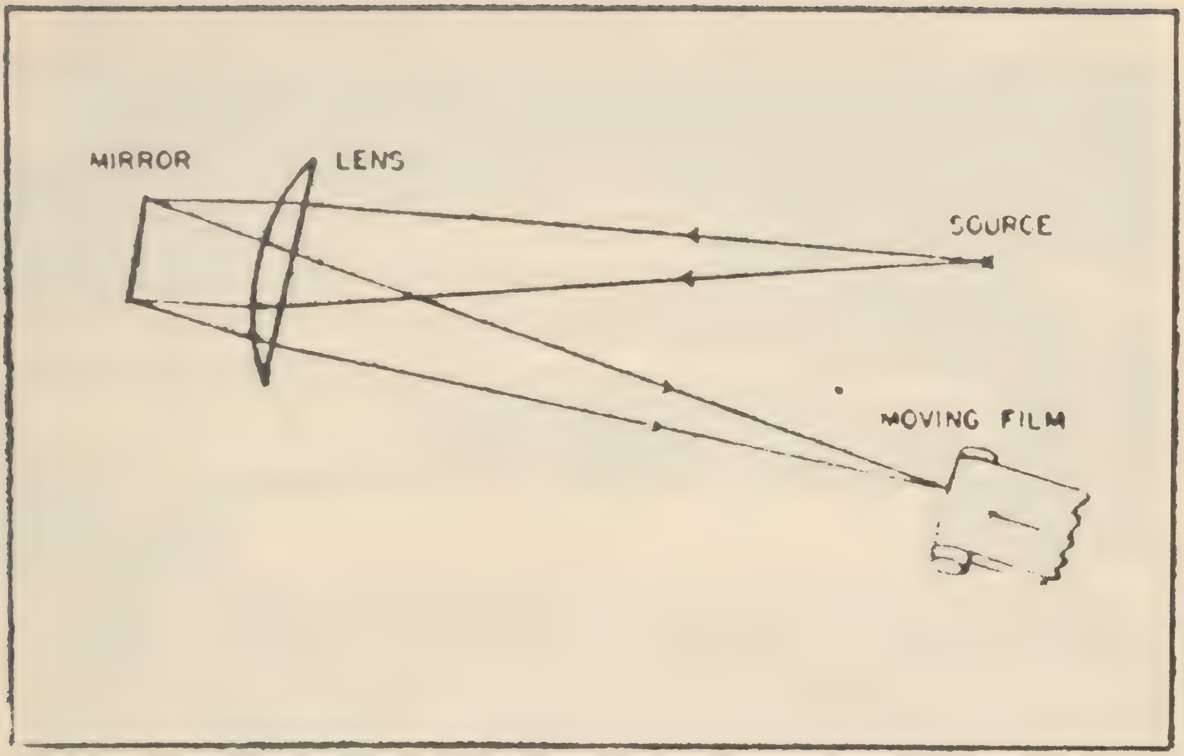


Fig. 1. Basic elements of the recording system

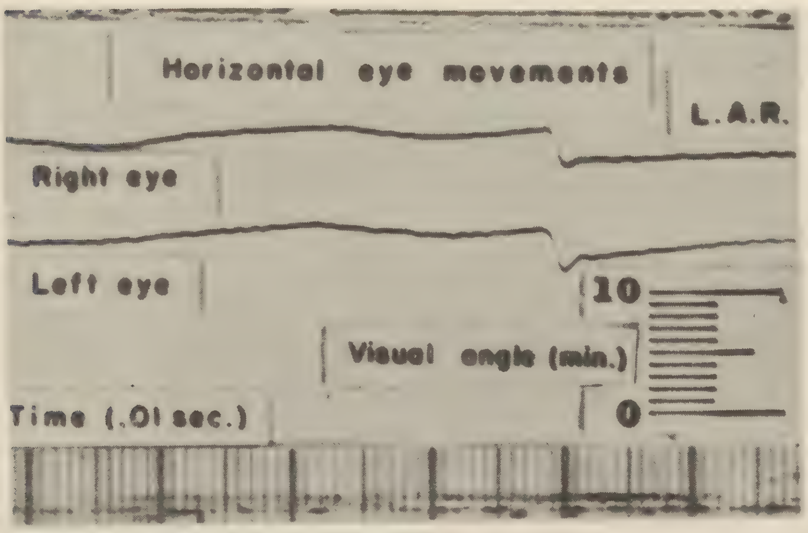


Fig. 2. Sample records of binocular eye movements

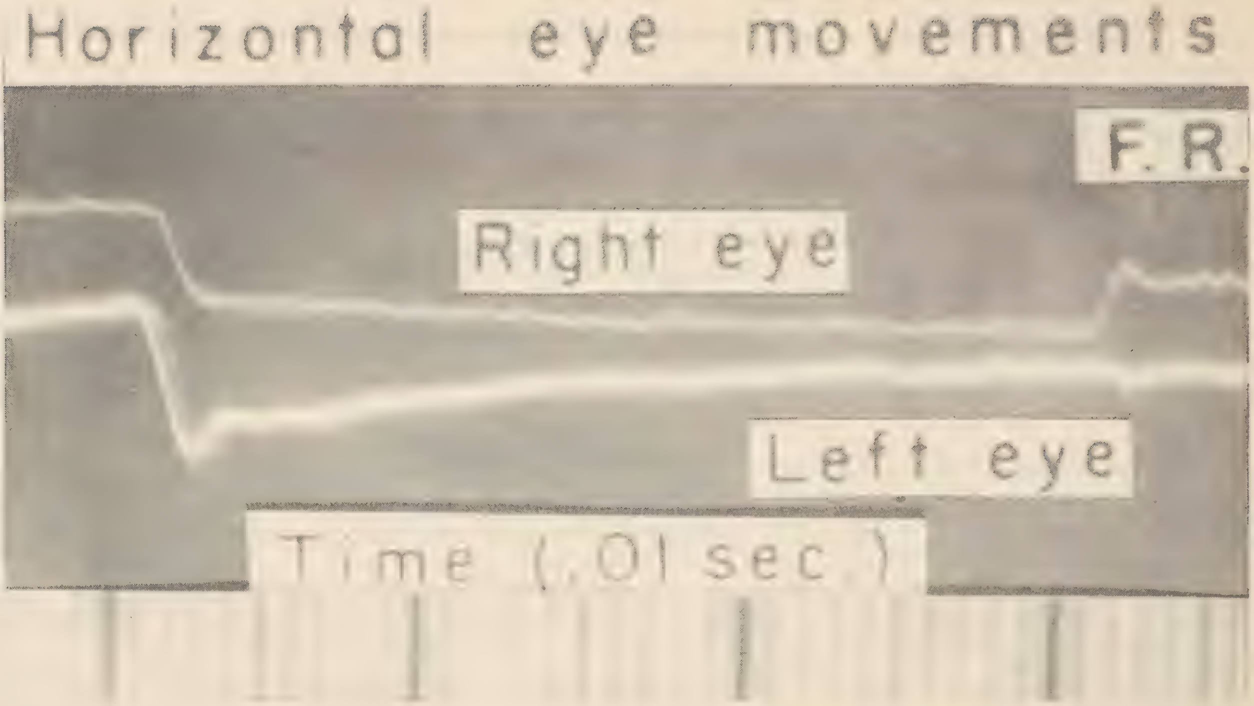


Figure 3. Sample records of binocular eye movements

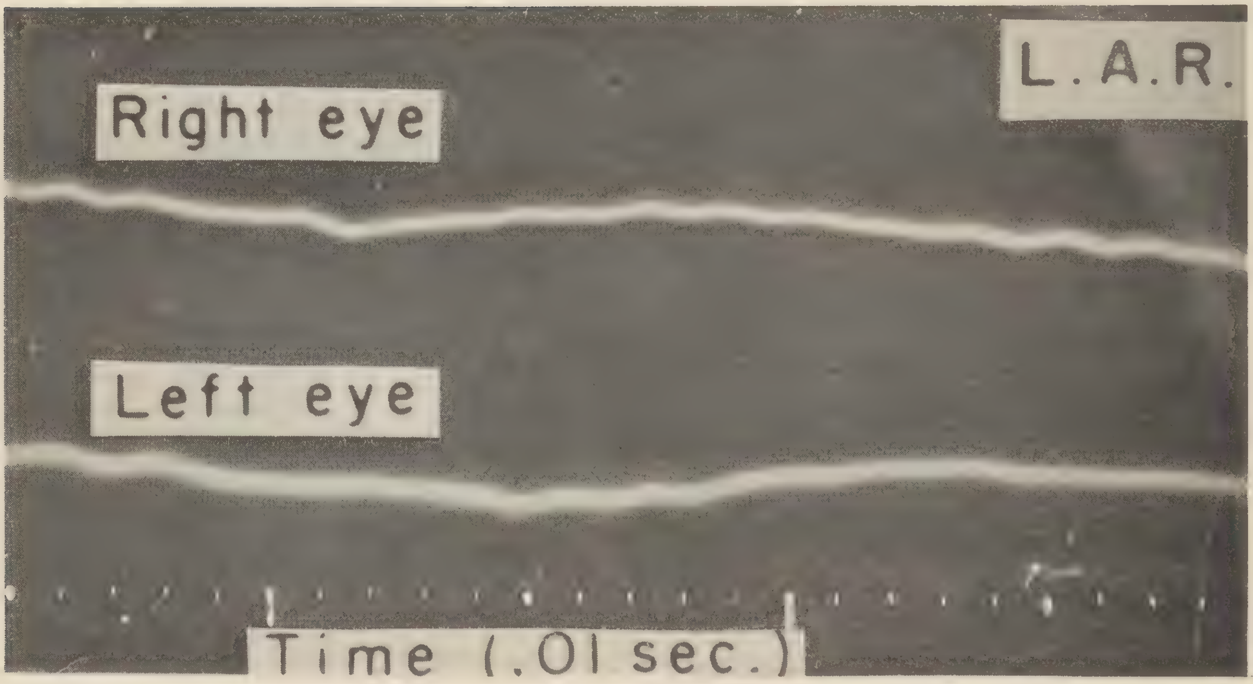


Figure 4. Sample records of binocular eye movements

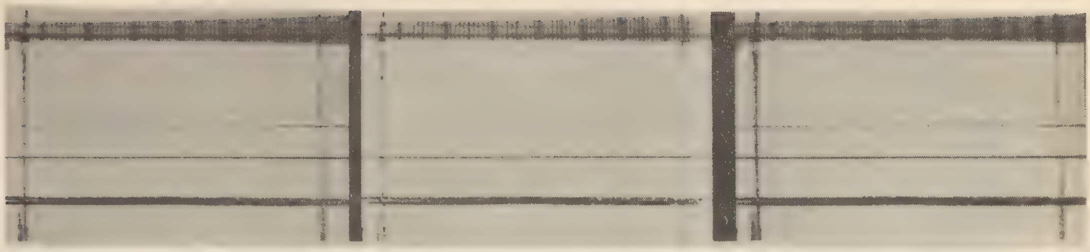

FIGURE 5

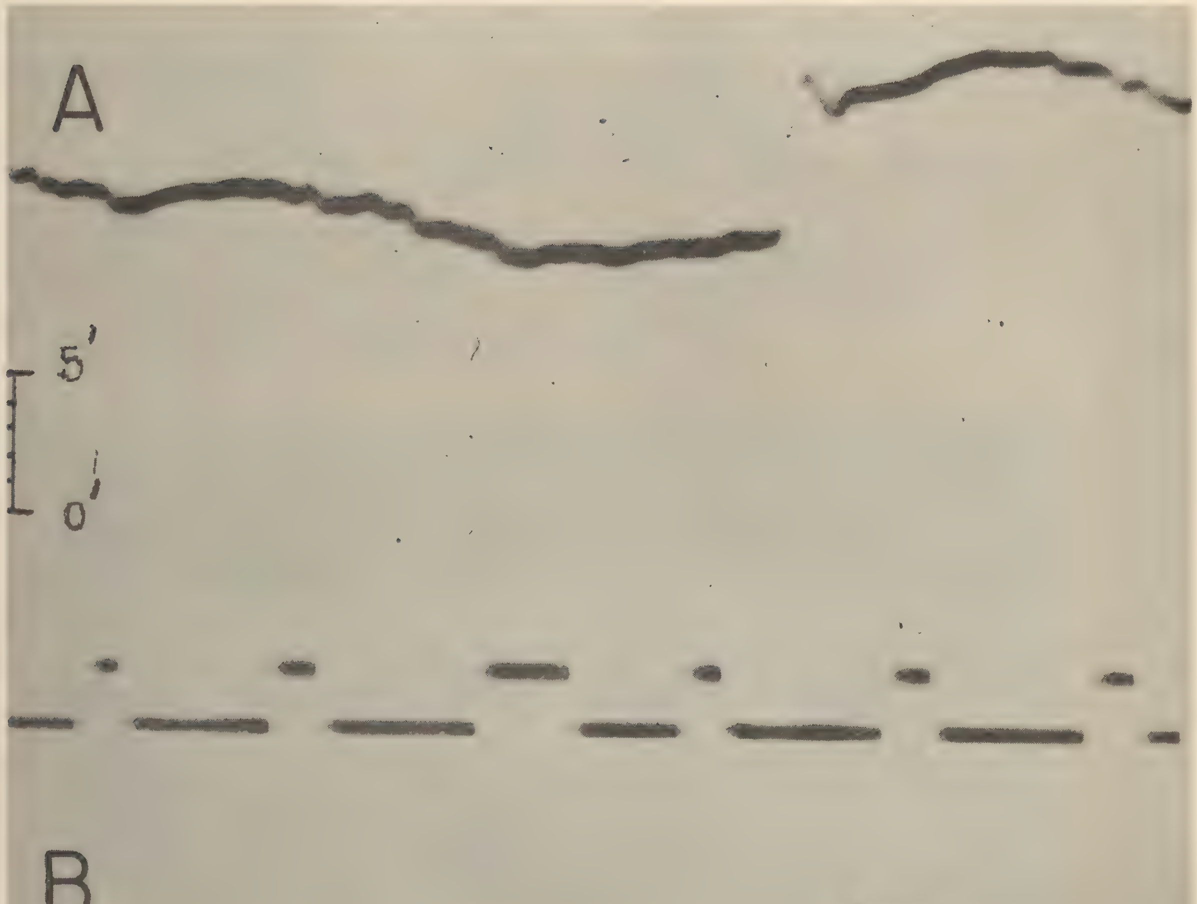


FIGURE 6

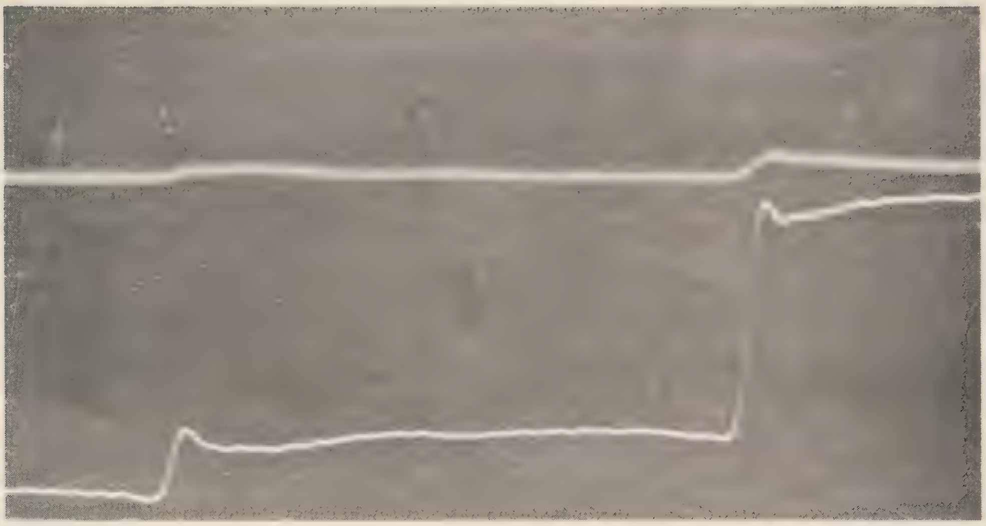

Figure 7. Comparison between corneal reflection (upper record, left eye) and contact lens mirror (lower record, right eye).

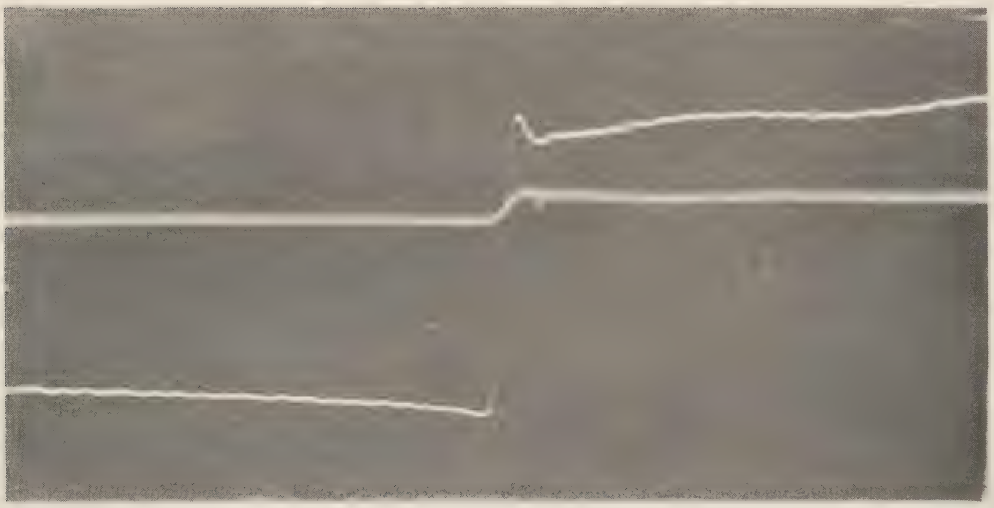

Figure 8. Same as Figure 7, except that contact lens is on left eye and corneal reflection is from right eye.

# RESEARCH ON ACCOMMODATION AND CONVERGENCE

# AT

# THE OHIO STATE UNIVERSITY

Glen A. Fry
School of Optometry
The Ohio State University

## Introduction

When a person is told to look at an object which is exposed to both eyes, and he reports that he sees a single clear image, we assume (1) that the eyes are immobile, (2) that the lines of sight (chief rays) connecting the point of fixation and the centers of the entrance pupils correspond in the sense that the images formed by the two eyes fall on corresponding points of the retinas, and (3) that these lines of sight are the primary ones in the sense that the image in each eye falls at the center of the fovea.

As a matter of fact none of these conditions is necessarily fulfilled. The eyes are constantly subject to a slight quiver (physiological nystagmus), and make occasional darts away from and back to the fixation point. The lines of sight from the two eyes that converge at the target do not necessarily correspond (fixation disparity). It may turn out that the image in neither eye falls at the exact center of the fovea. For the present purpose physiological nystagmus is small enough to be ignored. Furthermore, as long as the subject is not known to have an abnormal tendency or capacity for suppression of vision in one eye, and reports that he sees a single image of an object exposed to both eyes, the small amount of fixation disparity present can be ignored. Furthermore, if the target is clear it may be assumed that the image on each retina is at or very close to the center of the fovea.

Therefore, in the normal process of looking at an object, it can be said with the reservations indicated above that the primary lines of sight converge at the point of fixation. The amount of convergence is designated by the size of the angle formed by the primary lines of sight at the point of crossing.

It is more convenient to use the centers of rotation than the centers of the entrance pupil to define the angle of convergence because the centers of rotation are fixed with respect to the head. This simplification is possible because as the eye changes its direction of fixation one can find a fixed point in the orbit through which the primary line of sight will always pass, or at least a point from which it will be displaced the least as the eye moves from one fixation point to another. It is located on the line of sight about 13 mm. behind the cornea when the eye is looking straight ahead.

The line connecting the centers of rotation is called the base line. Convergence is said to be symmetrical when the point of convergence lies on a perpendicular bisector of the base line.

There are a lot of writers at the present time who want to use the concept of accommodation to cover a lot of things, including such things as changes in the refracting mechanism of the eye and changes in pupil size. Furthermore, since an observer can affect what he sees by manipulating the impressions after they arrive at the cortex,, some writers even want to include cortical processes as a part of the mechanism of accommodation. In the present discussion, however, we want to use it in its most restricted sense. That is to say, we want to think of the mechanism of accommodation as involving only changes in the crystalline lens of the eye induced by contraction of the ciliary muscle.

In some of the experiments about to be described a method of measuring changes in accommodation has been employed which takes into consideration only changes in the form of a lens and is not affected for example by the size of the pupil. In less controlled situations, such as found in a clinic, it is necessary to use a beam which fills the entire pupil and locate the point of sharpest focus in order to determine changes in accommodation. This sort of measurement is affected by the size of the pupil, the level of retinal illumination and the state of adaptation, but the effects produced by these factors are small and the changes in accommodation which are observed are for the most part produced by changes in the refracting mechanism of the eye.

For the purpose of measuring and specifying changes in accommodations, we define accommodation as a change in the refraction of the eye. The refraction of the eye at a given moment is defined as the reciprocal of the distance from the point for which the eye is accommodated to the spectacle point. Since the eye is not achromatic the point for which it is accommodated will vary with the wave length composition of the light. The spectacle point is used as the reference point instead of the cornea, principal plane or nodal point because it simplifies the calculation of the effect on accommodation produced by a lens which is placed at this point. Furthermore, the spectacle point which is 14 millimeters in front of the cornea lies very close to the focal point and may be assumed to coincide with it, and this facilitates the calculation of the position of the image formed by the refracting mechanism of the eye.

## The Need for Research on Accommodation and Convergence

Whenever a person attempts to perform a task, the two eyes converge at a certain point and the separate eyes focus at approximately the same point. During the course of the task he will look first at one point and then at another. The efficiency with which he can perform the task will depend to a large extent upon his ability to converge and accommodate for the various points and to switch quickly from one point to another. The problem is more complicated than it first appears because the two functions are tied together and because two different types of innervation are involved in the maintenance of convergence.

The study of accommodation and convergence is important not only from the point of view of finding out how we may use our eyes more efficiently, but it is necessary in order to understand the cause of eyestrain, fatigue and discomfort.

It is also necessary to understand the relationship between accommodation and convergence, because this information is useful in diagnosing lesions in the brain which affect one or the other of these functions.

## The Accommodation-Convergence Research Program at The Ohio State University

The present paper is not intended to be a survey of all research related to accommodation and convergence, but merely a summary of the work undertaken at The Ohio State University since 1935. As a matter of fact, the program was started by Dr. Sheard, in 1914, when the first courses in optometry were taught at The Ohio State University. Dr. Sheard and his co-workers contributed a great deal to our understanding of accommodation and convergence, and the work since 1935 has been an outgrowth from the beginning which he made. However, the present paper will attempt to summarize only the work done since 1935. The investigations to be referred to have been carried out by a number of persons, including the writer, his colleagues and students.

## Accommodation and Accommodative Convergence

By measuring the lateral phoria with different amounts of accommodation, one can determine the amount of convergence associated with accommodation. This is called convergence, and the ratio of change in accommodative convergence to accommodation has been called the A.C.A. ratio.

Studies have been made of the variation in this ratio at different age levels, and it has been found that this ratio remains practically constant, decreasing slightly as the age level increases. This constitutes part of the evidence that no more innervation is required to produce a given change in accommodation at one age level than at another, although the amplitude of accommodation decreases with age.

The variation of the A.C.A. ratio from individual to individual at the same age level has been studied and found to be quite variable, ranging from zero to values much in excess of what is needed. The cause of this variation has not been determined.

The same type of relationship between accommodation and accommodative convergence is found to exist in a group of squinters as in a group of normal subjects.

Transplantation experiments in lower animals, in which the internal rectus is attached to the stump of the external rectus and vice versa, are often cited as proving that the relation between accommodation and convergence is learned. These experiments have not been substantiated by experiments in human subjects where efforts to modify the relation by training have not proved successful.

Allen has recently completed a study on the time relationships between the response of accommodation and that of the associated accommodative convergence to a change in the stimulus to accommodation. An ophthalmograph was used to record the changes in convergence and the changes in accommodation were recorded with a movie camera by photographing at a rate of 64 frames per second, an image formed by reflection by the front surface of the lens. This study has shown that accommocation lags behind convergence associated with it by about a tenth of a second. This lag of accommodation behind the associated convergence is probably to be explained in the mechanism of stimulation of the ciliary muscle and the mechanics of imparting the effect of constriction of the muscle to the lens. Further study of these details is needed, but it appears safe at this point to conclude that the impulses sent to the ciliary muscles are synchronous and probably have a common origin in the central nervous system.

## Fusional Convergence

One of the instruments at The Ohio State University for the study of accommodation and convergence belongs to that variety of instruments called haploscopes. It has two arms, one for the right eye and one for the left eye, on each of which is mounted a target and an optical system for observing it. The stimulus to accommodation is controlled by moving the target toward the eye. The optical system is so designed that this change does not affect the apparent size of the target. Converggence is controlled by rotating the arms around the centers of rotation of the eyes. A special attachment makes it possible to measure the extent to which the eye is over or under accommodated.

While keeping the stimulus to accommodation fixed and equal for the two eyes,one can make the eyes diverge or converge by turning the arms of the haploscope in or out. Through quite a range of convergence the accommodation undergoes only a very slight change, but finally, as convergence increases, a point is reached at which there is a rapid increase in the rate of change in accommodation. These two limits at which

accommodation begins to increase and decrease rapidly are defined as the limits of fusional convergence, and it is believed that between these two limits the convergence of the two eyes is maintained by what is called the reflex fusion mechanism. It is believed to be reflex because there is no awareness that the images are being displaced from corresponding points of the two retinas as the stimulus for convergence changes, nor is the subject aware that his eyes are making a compensatory movement to bring the images back to corresponding points.

If convergence is maintained by such a mechanism, this mechanism would have to operate also while the stimulus to convergence is kept fixed except when the stimulus to convergence corresponds to the phoria position. At any other stimulus to accommodation the eyes would be continually drifting back to the phoria position and the fusional mechanism would have to be continually forcing the eyes to bring the images of the fusion stimuli back on corresponding points. A detailed analysis of this problem is being made at the present time by Stewart who is using an ophthalmograph to record fluctuations in convergence with various stimuli to convergence and divergence. About a dozen subjects have been investigated so far. Fluctuations in convergence have been found but do not appear to be a rhythmic drifting away from convergence and a quick movement back to fusion. In order to facilitate this analysis, he has studied the character of fusional movements induced by sudden small changes in the stimulus to convergence. In this connection he has measured the reaction time and the velocity of fusional movements.

One of the problems encountered in research of this type is that of differentiating fusional convergence from accommodative convergence. One can voluntarily accommodate, and this accommodative response has associated with it the accommodative convergence. Consequently, when a lateral diplopia is suddenly created by a base in or base out prism it is conceivable that this might be compensated directly by a fusional movement which is free from any associated change in accommodation or by a voluntary or involuntary effort which brings into play accommodation and accommodative convergence. Momentary blurring suggests that accommodation and accommodative convergence do come into play but are promptly replaced by fusional convergence.

The problem of differentiating accommodative and fusional convergence is even more acute in the situation where the stimulus to convergence has been increased to the point that it is necessary to throw the eye out of focus in order to maintain the eyes converged on the fusion targets. In this situation also the subject is not aware that the eyes are undergoing the compensatory movement to maintain fusion, and up to now we have not been able to formulate a satisfactory concept of the mechanism subserving fusion under these circumstances.

The fact that a different type of mechanism comes in when accommodation starts increasing or decreasing at a rapid rate is proved by the fact that some individuals completely lack the skill to throw accommodation out of focus in order to increase the range. Some individuals may know how to over accommodate to achieve this but not how to relax accommodation, or vice versa. Individuals who lack this skill can be trained to acquire it. In the case of those who have the skill, the amount that the eyes can be made to converge by means of a fusion mechanism before throwing the eye out of focus can usually be increased to a considerable extent with training. The extent to which the eyes can be made to diverge before throwing the eyes out of focus is much less susceptible to training.

Persons with a zero A.C.A. ratio present an opportunity for studying fusional convergence in pure form. The same holds for a person in which accommodation and accommodative convergence are both absent.

## Vertical and Fusional Movements

Vertical fusional movements also offer a unique opportunity for studying the character of fusional movements uncontaminated by effects of accommodative convengence.

## Significance of Relative Accommodation

By studying the relationship between accommodation and convergence at various levels of accommodation, it has been possible to prove that any change in accommodation is always associated with a change in accommodative convergence. In other words, it is impossible to make an effort to accommodate without having the accommodative response associated with a convergence response. This statement is quite compatible with the fact that at medium levels of convergence the eyes can undergo changes in accommodation while the overall convergence remains fixed. In this situation the changes in accommodation are associated with changes in accommodative convergence, but the changes in accommodative convergence are compensated by changes in fusional convergence.

This principle is beautifully illustrated at the extreme limit of divergence where the total range of relative accommodation is zero. The inability to accommodate while the eyes are maintained at the extreme limit of divergence is explained by the fact that in order to accommodate it is necessary for this accommodation to be associated with accommodative convergence, but it is impossible for the eyes to compensate this accommodative convergence through the operation of the fusional mechanism because this mechanism is already operating at its maximum capacity at the outset.

## Relation Between Accommodation and Convergence at the Maximum Level of Accommodation

A different set of principles operate at the maximum level of accommodation. At the zero level of accommodation there is no mechanical limit to the response of the lens in the sense that the lens will keep on changing form as long as the ciliary muscle can relax. At the upper limit, however, it is believed that the lens reaches a limit beyond which it cannot respond further to constriction of the ciliary muscle. Beyond this limit any effort to accommodate can be made manifest only by an increase in accommodative convergence. The existence of this relationship is clearly shown in certain individuals who can converge a great deal more at the maximum level of accommodation than is indicated by the accommodative convergence and fusional convergence found at lower levels of accommodation. This aspect of the problem is just as important for the theory of accommodation as it is for the relationship between accommodation and convergence. Data obtained with one or both eyes partially paralyzed should be capable of throwing a great deal more light on this problem. The data of this sort now available are somewhat conflicting.

## Relationship of Pupil Constriction to Accommodative and Fusional Convergence

Knoll has made a study of the relationship between pupil constriction, accommodation, and convergence. Although some subjects show a slight change in pupil size associated with fusional convergence, the response associated with accommodation and accommodative convergence is much greater. This again constitutes proof that fusional convergence and accommodative convergence involve different types of mechanisms.

Relation of Cyclophoria to Accommodative and Fusional Convergence

Another indirect approach to the relationship between accommodation and convergence is made possible through the study of cyclophoria. When both eyes turn simultaneously to the right or to the left no cyclophoria is induced, but if the two eyes converge, the eyes undergo an increase in excyclophoria. This shows that the pattern of innervation which is responsible for convergence differs from that involved in a change of fixation where one eye turns in while the other is turning out. Allen has made a detailed study of the changes in cyclophoria associated with changes in accommodative convergence as compared to fusional convergence and has found that there is no difference. This may mean that fusional convergence and accommodative convergence make use of the same center or mechanism for convergence in the midbrain.

DISCUSSION:

Dr. Scobee commented that all ophthalmologists are very much interested in the problem of the relationship between accommodation and convergence. He stated that he was especially glad to have Dr. Fry confirm that convergence does not decrease with age. Dr. Scobee reported that Colonel Byrnes had previously reported evidence of the same sort.

Col. Byrnes asked Dr. Fry if he regarded the difference in time relations between the processes of accommodation and convergence as due to the presence of a different kind of muscle tissue.

Dr. Fry stated that he would like to refer that question to his associate, Dr. Allen.

Dr. Allen stated that they began by assuming that the difference between time relations in accommodation and convergence was due to the difference between smooth and striated muscle, and that they then set out to prove that this was indeed the case. It is well known, of course, that the muscle which rotates the eye is striated, voluntary muscle tissue and is fast-acting. The ciliary muscle which controls accommodation is a multi-unit, smooth muscle in which individual cells respond separately thus giving it long latency. Dr. Allen stated that, although he did not yet have enough data to prove that the difference was entirely due to the difference in muscle tissue, it appears that that this difference is at least a large factor. The difference in reaction time of the two kinds of muscles is just about the right magnitude to explain the differences shown in the photographs that Dr. Fry presented. Dr. Allen stated further that age will greatly affect the speed of reaction of the smooth muscle but would not be expected to affect the speed of reaction of the striated muscle.

# REPORT OF THE WORKING GROUP ON REFLECTION OPTICS

T. Dunham, Jr., Chairman
University of Rochester

## Background

In February, 1950, the Subcommittee on Reflection Optics was established and asked to make a study of possible applications for military purposes of visual telescope systems which employ reflecting elements. The Subcommittee was reorganized as a Working Group on Reflection Optics in July, 1950. This study has now been essentially completed. A draft report has been prepared, and the final report will be presented to the Vision Committee in the near future.

The study has involved pure optics in the design and evaluation of telescope systems, but as the work progressed, it has become clear that special features of these reflecting systems influence the performance of the eye in ways that were not foreseen, and that some basic physiological problems also required investigation.

It is logical to ask why mirrors should be considered at all for use in telescope systems. For about 300 years all small telescopes for visual use were made with refracting objectives, erecting prisms and eyepieces. Almost twenty years ago Schmidt made what is probably the outstanding optical invention of the first half of the twentieth century when he corrected the aberration of a spherical mirror by means of a nearly flat plate of glass, figured with a weak aspherical curve on one side, and placed at the center of curvature of the mirror. Not quite ten years ago Maksutov, Bouwers, Gabor and Bennett independently hit upon the idea of substituting a simple meniscus lens for the aspherical corrector which is hard to figure on a production basis. The performance is almost as good on the axis, and the useful field is wider.

Several models of meniscus-corrected systems have been developed by Bouwers in Holland, and these have been put into limited production by the N.V. Optische Industrie "De Oude Delft." A Gregorian 20 x 50 telescope has aroused considerable interest because of its compact dimensions, light weight and inherently erect image without the use of prisms. A sample of this instrument was made available to the Subcommittee through the courtesy of Mr. Paul L. Pryor of the Photographic Laboratory at Wright Field. The same group has developed a binocular with the diameter of the primary mirror somewhat less than that of a aperture of the meniscus lens, and with a corresponding reduction in weight. A simple two-power monocular telescope has also been developed, based on the removal of the concave mirror to uncover a small refracting objective of shorter focal length than the reflecting system. Bouwers' group has also developed simple reflecting aerial cameras which combine several attractive features.

About 1939 the Kern Company of Switzerland developed a precision theodolite employing a two-element refracting objective and two Mangin mirrors. A primary image is formed within a small right angle prism on the axis of the first Mangin mirror. The second Mangin mirror, with its axis set at 90 degrees to the axis of the first mirror, refocuses the first image, just behind another right-angle prism, so that the observer looks through the eyepiece in the direction of the object. Recently the Kern Company has applied the same principle to the design of a 12 x 72 Periscopic Double Telescope for military applications. A considerable number of these instruments are in use by the Swiss Army.

Anticipated Advantages and Disadvantages of Reflecting Telescopes

At the outset of this study it seemed possible that reflecting telescope systems might have some of the following advantages: (1) improved correction of chromatic aberration and curvature of field, (2) simplicity of construction, (3) reduced cost of production, (4) reduced overall length, (5) reduced weight and (6) simple means for quick change of magnification. The following disadvantages were anticipated: (1) inaccessible focal surface, requiring relaying of the image by means of a secondary mirror, except in the case of aerial cameras, (2) possible high cost due to close tolerances on focal length when reticles are employed and difficulties involved in mounting mirrors with adequate precision, (3) a loss of about 15% in image brightness as compared with refracting systems, (4) possible increase in scattered light due to the use of first-surface aluminum mirrors, (5) unfavorable diffraction or physiological effects due to the introduction of a central stop. The extent and significance of each of these advantages and disadvantages required investigation.

Activities of the Subcommittee and Working Group

The Subcommittee was asked to do three things: (1) compile a bibliography of publications, including patents, describing previous work on reflecting systems, (2) compare the theoretical optical performance of reflectors and refractors, and (3) measure the resolving power and scattered light in a sample of the meniscus-corrected Gregorian telescope designed and produced by Bouwers.

1. Bibliography

A bibliography containing 228 references to published articles and 60 patents has been compiled under the direction of Dr. S. S. Ballard with the helpful co-operation of Mrs. J. D. Syke, Research Librarian of the Polaroid Corporation. Brief abstracts are included in this bibliography.

2. Tests of a 20 x 50 Bouwers' Telescope

A 20 x 50 meniscus-corrected Bouwers' telescope has been tested by Dr. H. S. Coleman, with the following results: The apparent field is 34°; transparency is 49% (as comparedwith approximately 62% to be expected from a system of this type with the most efficient reflecting coating); the KDC resolution is 94% at the center of the field and 25% at the edge of the field; vignetting is severe and probably accounts for a large part of the decrease in resolution at the edge of the field; contrast rendition is 91% on the axis (as compared with 96% for a high performance refracting telescope) when the objective is illuminated over 180°; interferometer studies show a maximum path difference of about 1/4 wave length, primarily due to fifth order spherical aberration. It is stated by the manufacturer that the instrument tested is an early model and that the aluminized mirrors are not representative of present quality.

3. Theoretical Studies of Meniscus-Corrected Telescopes

A study of the general properties of two-mirror reflecting telescope systems has been made by Mr. D. S. Grey. He has shown that the approximate formula given by Maksutov for the maximum aperature ratio of a meniscus-corrected system as a function of the f/ratio applies closely for Gregorian and Cassegrain systems. Spherical aberration is the most important defect of these systems, but secondary spectrum and coma are unimportant. Astigmatism and curvature of field can be held within satisfactory limits. Vignetting is serious in the design employed by Bouwers for the 20 x 50 telescope and this undoubtedly reduces resolution off the

axis to a significant degree. The mounting of mirrors requires much more care than the mounting of lenses. It seems impossible to meet the usual specifications for service telescopes (exit pupil 5 mm or more, apparent field 48° or more, magnification 10X or less) by means of reflecting systems. Accordingly, these instruments can only be used for special situations where high power and excellent optical performance are required. A study of off-axis Gregorian systems has been made, aimed at eliminating the obscuration at the center of the exit pupil which is objectionable to the observer unless it is held to a very small diameter. Some promising ideas were developed, but furtherstudy would be required to evaluate them.

4. Design of 68 x 70 Meniscus-Corrected Gregorian Telescope

A single type of reflecting telescope was selected for intensive study by Dr. Hopkins. This is the basic design in which the concave secondary mirror of a Gregorian telescope coincides with the rear surface of the meniscus lens, thus simplifying production problems. The N.A. is limited to 0.053 when the obscuring ratio is 0.3 (on the basis of diameter) and is limited to 0.024 when the obscuring ratio is reduced to 0.2. The magnification must be high, partly because the hole in the primary mirror limits the field of view rather severely, and it is desirable to enlarge the apparent field to about 48° to 50°; partly because the exit pupil most be held under 2 mm in diameter to avoid undesirable effects of the central stop; and partly in order to bring about an approximate matching of the field curvatures of the objective and the eyepiece. These considerations indicate that a magnification of about 60-70X is the most desirable, although this can be reduced somewhat without much loss in performance. The scale of the instrument should be large enough to provide at least 15 mm eye relief, if the instrument is to be employed effectively. A design for 68 x 70 telescope has been worked out in detail. Lt. Col. Alan E. Gee at the Frandford Arsenal very kindly constructed a model of this instrument for testing. It was possible to increase the aperture to 86 mm without introducing serious aberrations, and so the model is actually a 68 x 86 telescope. All aberrations are within the Rayleigh limit. The instrument could probably be scaled down to about 68 x 50, but if the size were reduced much further the eye relief would become undesirably short. The principal advantage of the reflecting system, as compared with a refractor of similar optical performance, is that the reflector can be made with about 40% of the length of the refractor, without sacrificing optical performance. There is of course a corresponding reduction in weight. The 68 x 86 telescope is available for inspection at this meeting, and will be tested critically in the near future.

5. Promising Optical Systems Which Have Not Been Studied

Several additional designs for reflecting telescope applications justify study. One of these is an off-axis system which eliminates the central stop ordinarily encountered in two-mirror reflecting systems. The studies by Mr. Grey and Dr. Hopkins indicate that off-axis systems may provide a satisfactory design. A second design which should be explored if possible is a crossed-axis Gregorian system, somewhat similar to the Kern theodolite, but with first surface (not Mangin) mirrors. This system would probably reduce the difficulties relating to eliminating stray light that are encountered in the usual Gregorian system, and there is a possibility that the central obscuration could be reduced and the field increased. A third promising application for reflecting systems is in various theodolites. A fourth application, well worth exploring, is for aerial cameras. The optical and mechanical simplification for large cameras could be very great, but this application lies outside the scope of the present study.

## 6. The Effect of a Central Stop on Visual Acuity

The influence of a central stop in an optical system has been investigated theoretically and photographically by Dr. Dunham. When the stop exceeds 0.2 the diameter of the aperture, there is a significant redistribution of light across boundaries of areas which differ in brightness, with a resulting reduction in local contrast. These effects become serious if the obscuring ratio exceeds 0.3. Dr. Blackwell and Dr. Tousey have carried out preliminary experiments to determine the effect of central stops on visual acuity. Twin stars and parallel lines were used as targets. Dr. Blackwell's results indicate that an obscuring ratio up to 0.3 has relatively little effect on visual acuity when binocular vision is employed, although individual observers differ to a marked degree in this respect, so that furtherobservations are indicated. Dr. Tousey's results show a significant reduction in acuity when central stops are introduced, but in this case also further tests are indicated.

## Conclusions

A straight-through meniscus-corrected Gregorian telescope system provides an errect image without the use of prisms, and is capable of giving excellent definition. All aberrations can be held within the Rayleigh tolerance. This system has advantages over an equivalent refractor which are marked when the magnification is relatively high (above 40X ordinarily), but which are not significant if the magnification is within the range ordinarily employed at the present time in military instruments. The length of a Gregorian telescope can be made about 40% of the length of a comparable refracting instrument, and the weight can be reduced to the same extent. It is not possible to say at this time whether the use of reflecting systems would reduce cost. In spite of the apparent simplicity of these systems, rigid requirements relating to the mounting of mirrors and tolerances on focal length might make them more expensive. Reflecting systems offer a simple basis for designing a telescope to provide a quick change from low to high magnification.

On the basis of preliminary studies, it seems unlikely that central stops up to 0.3 of the diameter of the aperture cause a significant reduction in visual acuity. Furtherstudies with targets of various types are much to be desired. If the preliminary results are substantiated, it will be evident that the failure of central stops to influence visual acuity is the result of imperfections in the optical performance of the eye.

It would be desirable to have studies conducted to determine the properties of optical designs based on crossed-axis meniscus-corrected Gregorian systems, in which the problem of diaphragming is simplified and in which it may be possible to decrease the obscuring ratio and to increase the field of view. It would also be desirable to compare rigorously the aberrations of refracting telescopes of the best design with the aberrations of the best Gregorian telescope of the same aperture that can be designed. Tests of the 68 x 86 Gregorian telescope designed by Hopkins and constructed by Colonel Gee, of a Bouwers' Gregorian telescope with satisfactory aluminum coating, and of a Kern periscopic crossed-axis Gregorian instrument are much to be desired.

The answer to the question whether reflecting telescope systems can be usefully employed by the Armed Forces depends on whether or not a short, light, high power telescope would be useful for any application. Detailed examination with high power and excellent definition of a target previously detected with a conventional low-power telescope seems more likely to be a useful application than any other than has been suggested to date. It would be desirable to test the effectiveness of a Gregorian telescope under field conditions, in order to find

out whether a short portable instrument of this type can be employed under service conditions, and if so whether the high magnification and good optical performance which it provides justify the employment of an additional instrument.

# The Bibliography on Reflection Optics

Stanley S. Ballard

Tufts College

One of the tasks undertaken by the Subcommittee on Reflection Optics of the Armed Forces-National Research Council Vision Committee, upon the formation of the subcommittee in January, 1950, was the preparation of a bibliograhy which would be useful to workers in this field of such increasing interest and practical importance. Special attention was to be given to technical papers which are relatively inaccessible because they appear in foreign publications or in journals of limited circulation. The applicable patent literature was also to be reviewed. The Reflection Optics Subcommittee was superceded in July, 1950, by the Working Group on Reflection Optics, but there was very little change in personnel.

I accepted the responsibility for the preparation of such a bibliography, and the results of our efforts can now be demonstrated, since the bibliography has been finished. Here is a very brief historical account of how it was done: In the early stages of its preparation, signal assistance was given by Dr. Theordore Dunham, Jr., of the University of Rochester, and Messrs. Rudolph Kingslake and Harold F. Bennett of the Eastman Kodak Company, all of whom supplied lists of important references and of pertinent patents. A great impetus was given the work when the Polaroid Corporation of Cambridge, Massachusetts, agreed to permit their Research Librarian, Mrs. Jacquelin D. Sykes, to cooperate on its compilation. Her assistance continued until the completion of the task, and it can be said with accuracy that without her excellent help and good hard work this bibliography would not have been completed in its present form and by the deadline date that had been set. Mrs. Sykes commenced by searching two abstract journals for the period 1935 to 1949: Science Abstracts, Section A (now called Physics Abstracts), and Chemical Abstracts. On the basis of this search and the information obtained from the sources noted above, she completed, in late June, 1950, a preliminary draft which contained about 100 literature references and listed 26 patents. I took copies of this draft with me to the July meetings of the International Commission of Optics and the London Conference on Optical Instruments, and gave copies to seven of the leading English and Dutch workers in reflection optics. They were asked to examine the draft for omissions, and to submit suggestions and additional references for inclusion in the final edition. Two "reminder" memoranda were sent them after my return home. Contributions were received from the following: R.L. Drew of C.R. Burch's group at the University of Bristol; Dr. E.H. Linfoot of the Cambridge University Observatory; A.J. Philpot of the British Scientific Instrument Research Association; E. W. Taylor of Cooke, Troughton, and Simms, Ltd. (all of England); and F. Hekker of Dr. A. Bouwers' Oude Delft Optical Company of Holland. The appropriate references which they submitted were included in the bibliography, and the search of the abstract journals was extended back through the year 1925 and forward to the current date of November, 1950. Also, it was decided to list the references alphabetically by senior author rather than chronologically as had been done formerly, and a brief statement was added to indicate the content of each patent, when this information could be obtained.

The present bibliography contains 228 literature references and 60 patents, for a total of almost 300 items. Very few references are dated prior to 1934. For the guidance of future workers in this field, it can be stated that the best sources of references were Physics Abstracts and the footnote references found in some articles but not themselves listed in the abstract journals.

(Editorial Note: The bibliography has been printed and distributed as this account goes to press.)

# MEASUREMENTS OF THE INFLUENCE OF CENTRAL STOPS ON VISUAL RESOLUTION

R. Tousey, M. Koomen and R. Scolnik
Naval Research Laboratory

In the reflecting telescope made by Bouwers, the exit pupil is hollow; that is, it is in the form of an annulus. This means that the central portion of the eye pupil is not used when the instrument is centered, and the light enters the eye through an annular area. The question arose whether a pupil of this type is as satisfactory from the point of view of visual acuity as the ordinary disc pupil.

We have undertaken a rather limited investigation of this. Conditions were selected to match approximately the Bouwers instrument and its probable use. Observations were made through artificial pupils of diameter 3 mm, which was the exit pupil diameter of the reflecting telescope, and with center stops from none at all up to 2 mm diameter. We restricted our observations to photopic vision and chose two brightness levels: 64 and 9 millilamberts. We did not try dimmer viewing conditions because it did not appear likely that an instrument with a 3 mm pupil was adapted to nighttime work, and because we felt that central stops would make most trouble when vision was photopic.

In the experimental arrangement, the observer viewed targets set up in a light tunnel. The complete target consisted of a large surround with the test target at the center. Most of the observations were taken with the distance between the observer and target ranging from 20 to 30 feet. At 20 feet the surround subtended an angle of 30° at the observer. The target and surround were illuminated by various arrangements of lamps or projectors.

Two types of test target were used. The first consisted of high contrast black and white bars printed upon a circular disk which subtended 4° at 20 feet. The second was a slightly modified Bausch and Lomb checkerboard of low (0.3) contrast. It consisted of a diamond grouping of four checkered squares, one of which contained a checkerboard grid much coarser than the other three. The coarse grid was to be resolved by the observer, while the others (which had the same integrated reflectance) were used for comparison only. The side of each checkered square subtended 8 minutes at 20 feet.

The observer looked through a phoropter which permitted easy selection of the spectacle lens which gave him best vision. Monocular vision was used. The annular artificial pupils were slipped over the eye cap of the phoropter and came as close as possible to the cornea (3 to 5 mm).

We made one set of artificial pupils by photography onto film. These were somewhat troublesome to use because one's eyelashes kept getting them dirty and we had to clean them carefully a number of times during a run. To avoid this trouble, we made another set out of metal without any transparent support. The central disc was held in place by means of a pair of fine cross wires, of diameter 0.002". As far as we could see, the cross wires were invisible and had no effect on vision.

The acuity thresholds were determined by changing the distance between the observer and the target. To do this readily we placed the observer and his equipment upon a carriage running on rails. The observer operated a switch to move himself forward or backward. The target was first selected which was just above threshold for 20 feet. Then the observer moved back and determined the threshold range as accurately as possible. We used as criterion of threshold the condition that the observer could just resolve the checkerboard or the bar pattern. We did not determine probability of seeing curves largely because it takes longer to do, and because our

precision and reproducibility appeared entirely satisfactory for the present investigation. We also felt that other factors, such as difficulty in maintaining exact centering of the pupils, introduced enough error to make it not worthwhile to strive for ultimate accuracy.

Results obtained with the high contrast barred targets for a 3 mm pupil are shown in Figure 1. The curves are for three observers and two brightnesses. The size of the central stop is plotted on the abscissa scale and the experimentally determined acuity for each stop size is plotted as the ordinate. Acuities are expressed as the angular distance between centers of two adjacent black bars. Within experimental error there was no change in acuity for central stops of less than 1 mm diameter. The 1.5 mm stop produced a perceptible loss in acuity, and the 2 mm stop had an effect of 10 to 15% at the high brightness and 14 to 44% at the low brightness.

The observers felt, after making these observations, that the presence of central stops might have a greater effect if some other type of test object were used. For this reason the low contrast checkerboards were tried.

The results for the low contrast checkerboard targets are given in Figure 2 for the 3 mm pupil, three observers, and two brightnesses. The angles refer to the subtense of a black plus a white square in the resolved pattern. It is at once apparent that the checkerboard targets produced about twice as great effect as the bars. There was no significant change in acuity with the 0.4 mm central stop in place, but the 1 mm stop produced a definite loss in acuity, of the order of 15% for two observers and 4% for the third. For the 2 mm stop, the acuity losses ranged from 35 to 68%.

The experimental error in most of the plotted points was of the order of 5 to 10%. By carefully and repeatedly comparing vision of a particular target adjusted just above threshold, first through the open pupil and then through the pupil with a given central stop, it was possible to detect a very small loss in acuity, probably well under 5%. This was done with the 0.4 mm stop and the open pupil, using checkerboard targets, and no difference in vision was detectable.

We found that, for the annular pupils discussed above, the effect of spherical aberration of the eye was negligible. In other words, for a 3 mm pupil, the optimum spectacle correction was the same for central stop sizes varying from zero to 2 mm. However, when we attempted the experiment with the natural pupil and central stops larger than 2 mm. it became apparent that increasingly negative spectacle corrections were required to obtain optimum acuity. This was due to the undercorrected spherical aberration in the outer zones of the observer's eyes. The curves of Figure 3, which are averages for three observers at a brightness of 9 mL, show this effect. The pupil diameter in this case was about 6 mm. The upper curve shows the acuities when the spectacle correction was not changed as the size of the central stop was increased, and the lower curve shows acuities when the spectacle was optimal for each stop size. The curves run together for central stop sizes below 2 mm, indicating that the aberration was negligible in this region. The lower curve shows that, where the pupil was large and optimum spectacle corrections were used, the acuity with a high contrast grating target was reduced by about 45% for a 5 mm central stop, whereas a 2 mm stop caused a rather negligible deterioration in acuity.

Finally, it is fair to ask the question, what causes the lowered acuity when large central stops are used? There are two possible causes. First, the retinal illunination is lowered, and therefore the target appears less bright. Second, it seems likely that the outer portions of the eye lens and optical system are less perfect than the central portions, since they include a much larger area, and

since the rays have to travel further in the optical medium. Also, these rays strike the retina at oblique incidence, and therefore more cones would be included in an image of a given cross section than in the case of normal incidence.

Although the introduction of central stops must alter the diffraction pattern somewhat, we were unable to observe any effects which appeared due to this cause.

We were not able to investigate all these possible causes, but it was a simple matter to determine whether the loss of acuity was due to reduced retinal illumination alone. For each type of target we obtained the acuity versus brightness curve with the 3 mm pupil. We calculated the reduction in apparent brightness due to the introduction of the central stops and took into account the Stiles-Crawford effect, though this was not very important for the 3 mm pupil. This gave us sufficient information to plot curves of acuity versus central stop size. These are shown in Figures 4 and 5 and are to be compared with the respective curves of Figures 1 and 2.

It can be seen that the reduction in apparent brightness caused only a small fraction of the observed loss of acuity, in all cases less than 1/4. The principal cause must therefore lie in the image-forming properties of the outer zones of the eye pupil and in the structure of the retina.

As a direct check on these conclusions concerning hollow exit pupils, we tried one side of a 7 x 50 binocular with stops placed over the objective so as to produce hollow exit pupils of 3 mm outer diameter and inner diameters ranging from 2 mm down to zero. Outdoor brightly illuminated targets were used in most cases. The experiments were not too carefully performed, but the conclusions were substantially the same. Central stops over 0.6 or 0.7 mm in diameter in the exit pupil reduced the acuity obtained with the instrument.

The conclusion from our work is that, for a 3 mm pupil, central stops up to 0.5 mm diameter have no effect, but that stops greater than 0.9 or 1.0 mm diameter should be avoided.

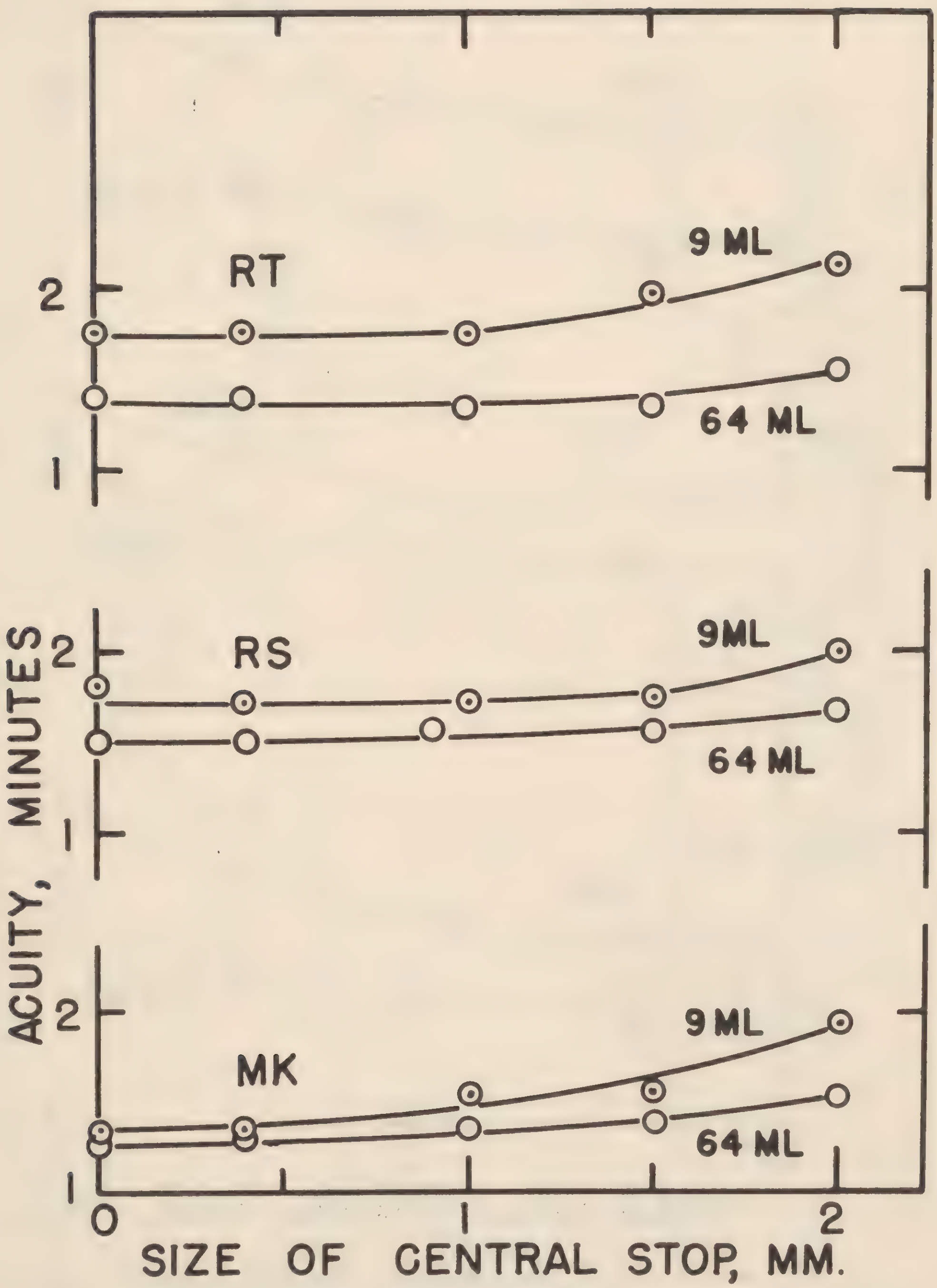


Figure 1 The effect of various central stops in a 3 mm pupil, as determined with high contrast grating test objects. Brightness levels used were 9.0 and 64 millilamberts (as measured with the natural pupil) and 3 observers were used.

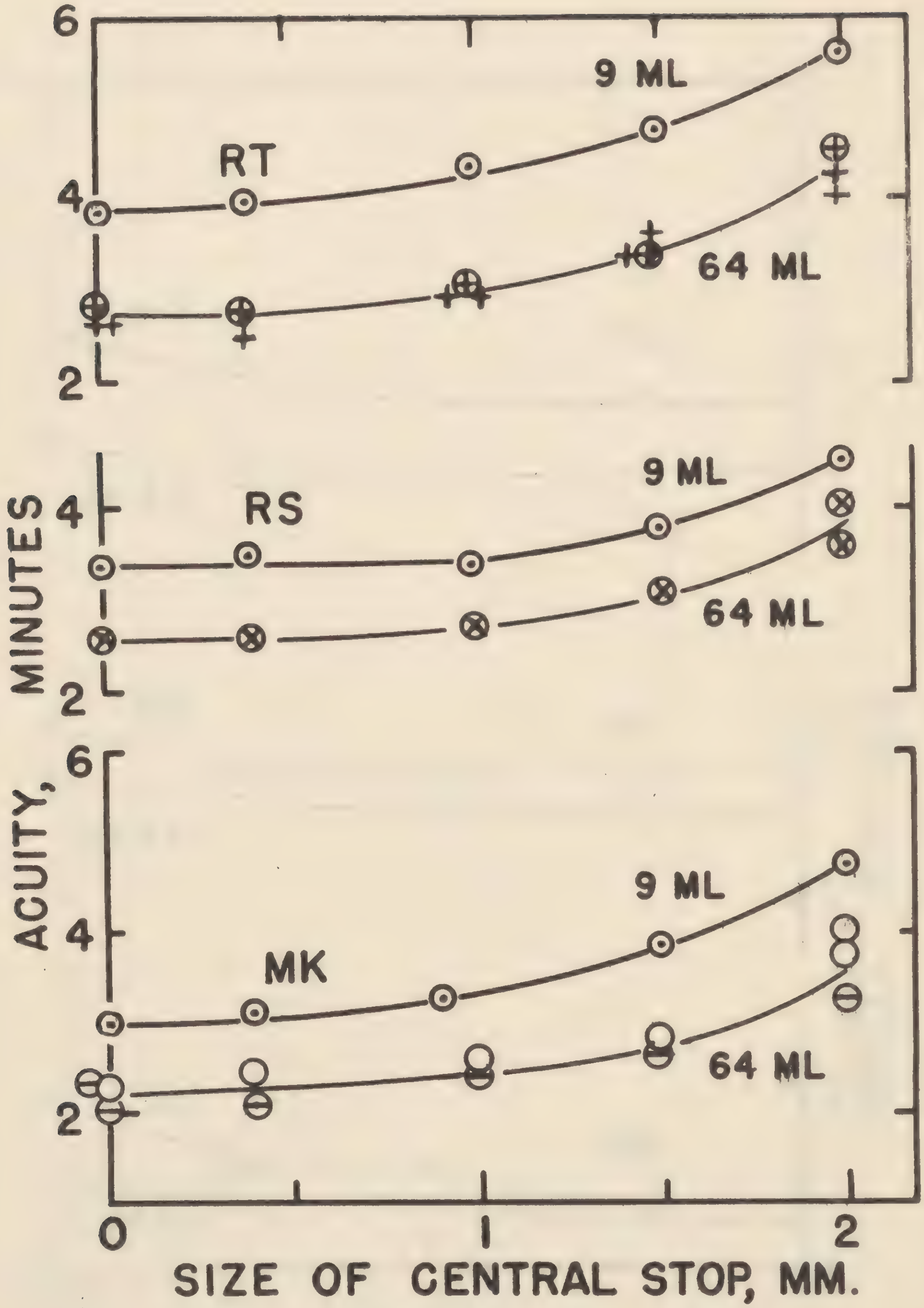


Figure 2 The effect of central stops in a 3 mm pupil, as determined with checkerboard test objects of contrast 0.3. Other experimental conditions as in Figure 1.

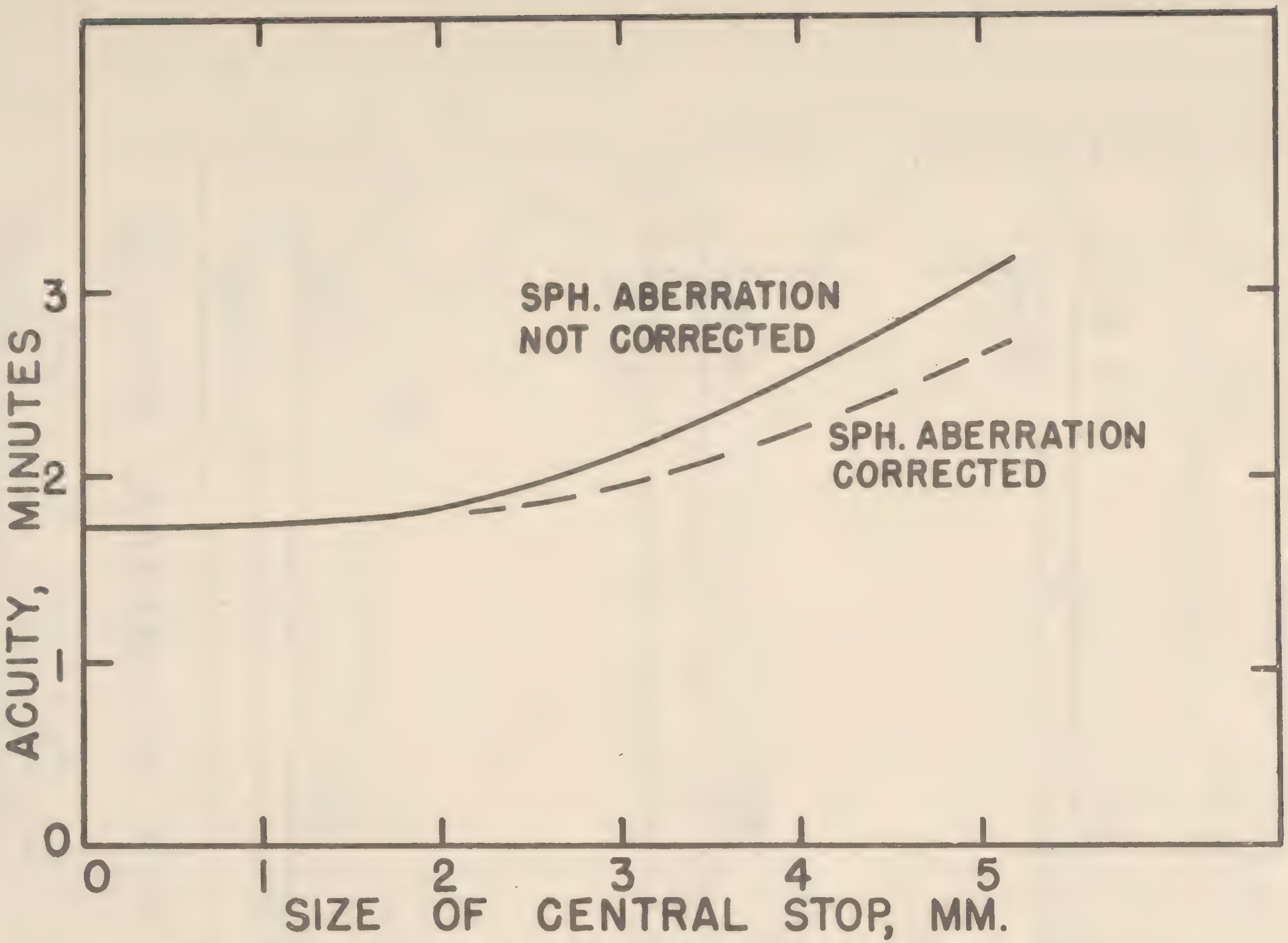


Figure 3 The effect of central stops in a 6 mm pupil. The upper curve is for the spectacle correction which gave optimum acuity with no central stop. The lower curve was obtained using the optimum spectacle correction for each central stop. The curves represent the averages for 3 observers with eyes having undercorrected spherical aberration. The high contrast grating test object and 9.0 mL were used.

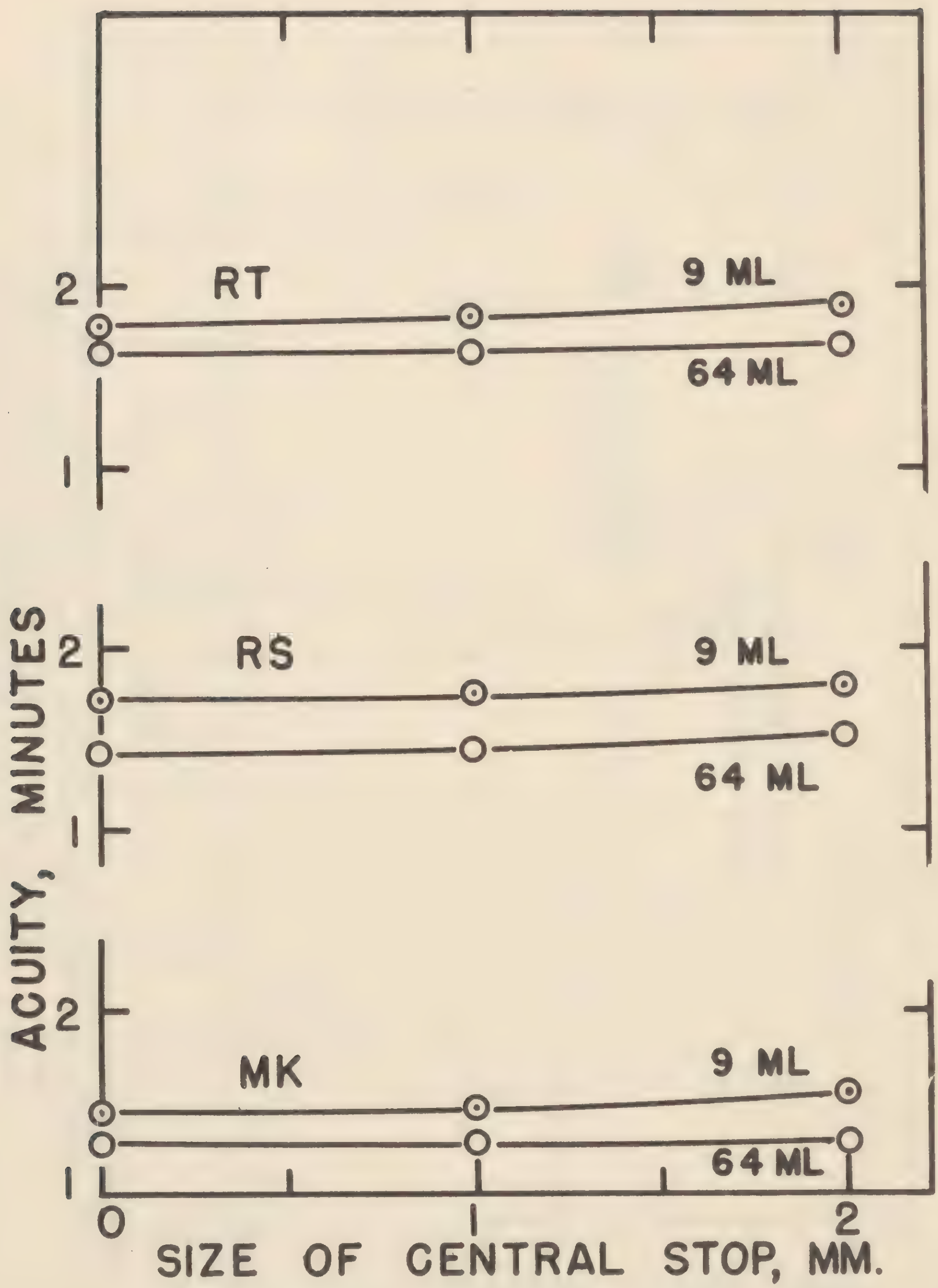


Figure 4 The effect of central stops in a 3 mm pupil, predicted from the diminution of brightness caused by the central stop; high contrast grating test object. Compare with Figure 1.

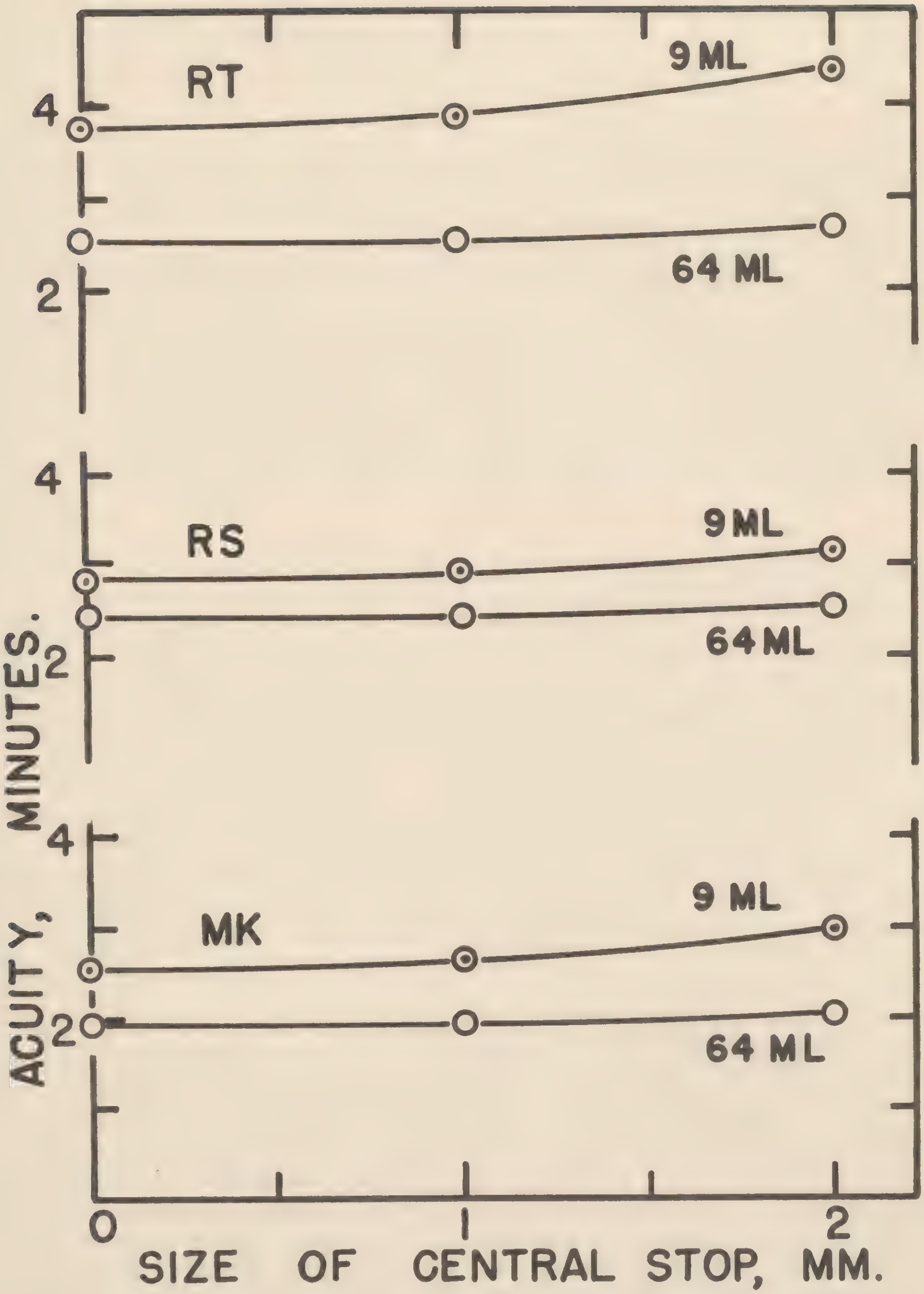


Figure 5 The effect of central stops in a 3 mm pupil, predicted from the diminution of brightness caused by the central stop; checkerboard test object of contrast 0.3. Compare with Figure 2.

# Measurements of the Influence of Central Stops Upon Visual Resolution

H. Richard Blackwell
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## Introduction

Dr. Dunham has indicated that the design of telescopes employing reflection optics usually involves the inclusion of an area of obscuration in the center of the exit pupil. In evaluating the advantages and disadvantages of reflection optics systems in comparison with conventional refracting systems, the question arises to what extent the area of obscuration will affect visual performance. This question was raised by Dr. Dunham at the May meeting of the Vision Committee in Ottawa. At that time, Dr. Tousey and I agreed to explore the influence of central areas of obscuration upon visual resolution. Since only exploratory study of the question was desired, it was believed to be necessary that available experimental apparatus be employed. Since the experimental arrangements which Dr. Tousey and I had available to us were considerably different, it was thought that study by both of us would be desirable.

The speaker has not discovered any experimental evidence reported in the literature which is directly pertinent to the question of the influence of central areas of obscuration upon visual resolution. There appear to be three possible bases for an expected change in visual resolution when the central area of the pupil of the eye is rendered ineffective by an opaque stop. In the first place, a central stop reduces the illumination of all parts of the retinal image. This effect is more significant than would be expected on the basis of the area of the stop alone because of the Stiles and Crawford effect. (Stiles and Crawford have shown that rays passing through the center of the human lens are more effective in producing a "visual effect" than rays passing through the periphery of the lens.) To illustrate the magnitude of this effect, a 1.2 mm. central stop in a 3.0 mm circular pupil is expected to reduce the overall retinal illumination effectively by about 20%. Such a reduction in overall retinal illumination would be expected to reduce visual resolution, at least under some conditions.

It is well known that the human eye exhibits a considerable spherical aberration. Hence, a central stop would result in a change in the refractive condition of the eye which might be expected to influence visual resolution provided the eye did not adjust its accommodation to compensate for the refractive change. Whether or not the eye will adjust accommodation to compensate depends upon the degree to which the accommodative process is dependent upon the sharpness of the retinal image alone. Preliminary results have been obtained in experiments conducted by the speaker in an entirely different connection which suggest that accomodation does not depend entirely upon retinal image sharpness but also upon accommodative habits which appear to be related to perceived distance. It was shown that when circular artificial pupils are employed, the eye does not compensate for the refractive change produced by the artificial pupil but instead seems to maintain the focus adjustment employed with natural pupils. Because of spherical aberration, accommodative adjustment should occur when artificial pupils are introduced, but the adjustment is apparently not made. It was hypothesized that the accommodative adjustment was not made because of accommodative habits which are related to the perceived distance of objects. If such an accommodative mechanism exists, its effect would presumably be greatest when cues to distance are most abundant. Hence, we might predict that there would be a less adequate accommodative adjustment to the refractive change produced by central stops for binocular than monocular vision. If this accommodative mechanism

exists, we would further predict that visual resolution would be more influenced by central stops with binocular than monocular vision.

Finally, the introduction of central stops would be expected to influence the retinal images of stimulus objects through diffraction effects. As Dr. Dunham has reported, the central peak of the diffraction pattern of a point source stimulus object will actually be sharpened by the introduction of a central stop. The percentage of light "thrown" into the outer bands increases, however, when central stops are introduced. One of these effects would be expected to aid, the other impair resolution. The net result cannot be predicted. It is, moreover, entirely possible that the net effect would differ depending upon the type of resolution test object employed.

The matter is further complicated by the fact that the effects of diffraction described by Dr. Dunham apply to in-focus images. It is to be expected that at least most subjects will exhibit refractive errors of a few tenths of a diopter even without the introduction of central stops. The introduction of central stops is expected to increase the refractive error unless accommodative adjustment compensates adequately for the refractive change due to spherical aberration. Thus, we have to consider out-of-focus diffraction effects, rather than in-focus diffraction. The calculation of out-of-focus diffraction patterns has been undertaken by a procedure which represents a modification of the calculational technique reported by Lansraux. It is apparent that refractive effects of a few tenths of a diopter are sufficient to produce what appear to be significant changes in the retinal images. The changes are in general of the sort reported by Dr. Dunham for the in-focus case, but irregularities occur, the effect of which is difficult to predict.

In view of the apparent variety of possible effects of central stops upon visual resolution, it was decided that exploratory measurements should be made to investigate the approximate magnitude of the effect on visual resolution. The apparatus employed was constructed under the office of Naval Research Contract N5 ori- 116, Task order V; project NR 142-106.

## II. Experimental Conditions for the "Twin Star" Experiments

In the first experiments to be reported here, the resolution of the eye was measured by the ability of the eye to detect a difference between a pair of point light sources and a single light source of double the intensity. The horizontal separation between the pair of point sources was varied until the subject was able to detect that the pair of points was different from the single point source of twice the intensity. The point sources were seen against a general background which subtended six degrees at the eyes of the subject and which had a brightness of 7.62 foot-lamberts. Fixation and orientation were provided by two points which were separated vertically by 6 minutes. The test point sources were located midway between the fixation points vertically, and were allowed to spread horizontally to the extent necessary for the subject to detect differences from the standard point source of double intensity. The subject viewed the point sources from a distance of 15 feet in real space.

The psychophysical procedure was of the "temporal forced choice" variety. In this method, each stimulus presentation consists of four temporal intervals demarcated by an electric buzzer. In three of these intervals, the single light source is presented; in one, "twin stars" are presented. The interval containing the "twin stars" varies randomly among trials and it is the task of the subject to indicate which of the time intervals contains the "different" stimulus. The subject must choose the interval most likely to be "different" on each presentation regardless of his awareness of a difference. Thus, the subject may employ any basis available to him in selecting his response.

The points of light are presented by apparatus employing the principle developed by Hulburt and his colleagues. A plano-convex condenser is employed as a mirror to form greatly demagnified images of a series of points of light. The points of light are the projection lenses in a series of small projectors which may be positioned horizontally along an optical bench. The condenser is laminated to a sheet of opal glass so that the image of the points of light are seen against a general field of approximately uniform brightness.

Data are presented for monocular and binocular vision. In each case, the subject was required to maintain his bite on a positioning device consisting of a dental impression so that his head was fixed in a position which could be reliably repeated. Reticles were positioned in a holder which was located just forward of the eyelashes of the subject's eyes. These reticles were prepared by the Bausch and Lomb Optical Company by first chemically applying a film of silver to a cover glass and then scraping away portions to correspond to clear aperture.

Data are presented in terms of the resolution threshold, here defined as the angular separation of the "twin stars" at which the subject was able to report the temporal interval correctly fifty percent of the time, chance successes having been eliminated in the standard statistical manner. The thresholds were obtained from experimental data expressed in terms of the proportion of the time correct answers were given as a function of angular separation of the "twin stars." The thresholds and their standard errors were determined by the probit analysis described by Finney in his recent book of the same name.

## III. Twin Stars

### Monocular Data

The first experiment was conducted with one subject with monocular vision. Monocular vision was employed since only one set of reticles was available. The unused eye was covered with a black patch. Threshold determinations were made with each of four reticles consisting of a 3.0 mm. diameter pupil with a central opaque stop of variable size. It was established experimentally that the pupillary diameter of the eye of the subject employed exceeded the 3.0 mm. outside diameter of the reticles. This was established by mapping the extents of the visual field with each of a series of artificial pupils in one place. It was shown that the extent of the visual field increased in direct proportion to the diameter of the artificial pupils employed. It was concluded, therefore, that the artificial pupils were the limiting pupils up to 3.0 mm. size which was the largest pupillary employed aperture. The experimental resolution thresholds are given in Table I.

Table I: Monocular Resolution of "Twin Stars"

Observer: BC

| Case # | Outer diameter of aperature (Millimeters) | Diameter of central stop (Millimeters) | Threshold Resolution (Minutes of arc) |
|---|---|---|---|
| 1 | 3 | 0 | 0.808 |
| 2 | 3 | 0.4 | 0.940 |
| 3 | 3 | 0.8 | 0.957 |
| 4 | 3 | 1.2 | 1.032 |

Significance of difference from Case # 1

| | |
|---|---|
| # 2 | P = 0.14 |
| # 3 | P = 0.01 |
| # 4 | P = 0.002 |

Combined significance P = 0.00007

## Conclusions

The threshold measurements presented above revealed that there was a small but significant loss in visual resolution which occurred when central stops were introduced, the loss increasing progressively as the size of the central stop increased. Since these measurements were regarded as empirical check only, it is not possible to provide an entirely adequate explanation for the physiological basis of the effect.

The possible effect of the stops in reducing the overall retinal illumination was not experimentally checked. However, two series of experimental data obtained in a completely different connection permit us to conclude that this effect was probably not entirely responsible for the observed loss in resolution capacity. In one of these experiments, the effect of increasing background brightness upon the resolution of "twin stars" was investigated. It was found that the resolution threshold increased from 0.674 minutes for a 60 footlambert background brightness to 0.860 minutes with a totally dark background. These data do not permit us to determine the exact shape of the functional relation between background brightness and resolution threshold. It would perhaps appear unlikely, however, that a 20% change in background brightness could have an appreciable effect upon the resolution threshold when the effect of background brightness is so small over so large a range.

The second set of data reveal the relation between resolution threshold and the brightness of the twin-stars, background brightness being constant. It was found that resolution threshold reaches a minimum for brightness approximately ten times the detection threshold intensity for the stars and increases for brightnesses either greater or less than this value. It is possible to determine the expected change in resolution threshold resulting from a reduction in the brightness of the "twin-stars" for each of the central stops from these data. The results are presented in Table II

Table II: Monocular Resolution of "Twin Stars"

| Diameter of central stop (Millimeters) | Obtained resolution threshold (minutes of arc) | Predicted threshold (minutes of arc) |
|---|---|---|
| 0 | 0.808 | 0.81 |
| 0.4 | 0.940 | 0.82 |
| 0.8 | 0.957 | 0.83 |
| 1.2 | 1.032 | 0.86 |

It was concluded that the observed effect was in part to be expected on the basis of the overall reduction in retinal illumination produced by the central stops, but that this explanation is not sufficient for the entire effect.

The possibility that the remainder of the loss in resolution was caused by inadequate accommodative compensation for the refractive change introduced by the central stops was investigated in the following manner. The refractive condition of the eye was measured with a stigmatoscope (or oculometer) with each of the reticles in place before the eye. The stigmatoscope consists of a point source of light which may be moved in apparent space by optical means. If the subject sets the point for minimum subtense, the refractive condition of the eye may be computed from the position of the light in apparent space. The stigma is introduced by means of a part silvered mirror and appears superimposed on objects in object space. The stigma was flashed on and off at a rate of approximately one per second to reduce the possibility that the subject might accommodate for it. The subject makes repetitive settings to minimum size and the average of these settings is taken as the measure of the refractive condition of the eye. Since the subject may adjust accommodation in order to compensate for a refractive change introduced by the central stops, the stigmatoscope measurements represent the resultant refractive condition. The results of 30 settings with each reticle are presented in Table III.

Table III. Monocular Accomodative Condition

| Central stop (millimeters) | Refractive error (diopters) | Resolution threshold (minutes of arc) |
|---|---|---|
| 0 | -0.11 | 0.808 |
| 0.4 | -0.63 | 0.940 |
| 0.8 | -0.13 | 0.957 |
| 1.2 | -0.32 | 1.032 |

These results are somewhat perplexing since there is no orderly relation here between the resolution threshold and the refractive error. Furthermore, one might perhaps expect an orderly progression in refractive error as the size of the central stop is increased, but such is not the obtained result. However, it should be emphasized that the refractive errors due to spherical aberration and any accommodative adjustments which the observer may make are combined in some unknown manner in these measurements. Thus, the simple expectance of greater refractive error as the size of the central stop is increased might fail to be realized. Also, the relation between refractive error and resolution threshold might be expected to be complex if resolution threshold were influenced by the overall loss of light and the diffraction effects of the central stops as well as by refractive effects.

There is no direct manner in which to investigate the possibility that diffraction effects are responsible for changes in visual resolution which occur when central stops are introduced. The diffraction explanation will be reserved to account for effects which are not apparently explicable in other terms.

The measurements reported above were made in a week prior to the June 23 meeting of the Subcommittee on Reflection Optics and thus were, of necessity, of a preliminary sort. At the June meeting, plans were made for more complete measurements so that some of the questions of interpretation could be answered.

It was decided that in the further measurements the following features would be included:

1. An experimental check on the effect of overall loss of light equivalent to the loss produced by central stops, with allowance for the Stiles and Crawford effect.

2. Separate measurements of the refractive change introduced by the central stops and of the refractive condition when accommodation was allowed.

3. Binocular rather than monocular measurements, in order to maximize the effects as described above.

IV. Twin Stars: Binocular data

In order to make binocular measurements five pairs of identical reticles were obtained from Bausch and Lomb with central stops of 0.3, 0.6, 0.9 and 1.2 mm. diameter. With the exception that the subject was permitted to use binocular vision, all experimental conditions were just as before. In addition to the subject employed previously, there were two additional subjects. In addition to the resolution measurements made with each reticle, measurements were made with natural pupils. These measurements were made both with and without neutral filters which reduced the overall transmission to a larger extent than the maximum to be expected with the largest central stop, after correction for the Stiles and Crawford effect. The results for the seven experimental conditions are presented in Table IV.

Table IV: Binocular Resolution of "Twin Stars"
(Minutes of arc)

| Observer | No reticle | Central Stop (millimeters) 0 | 0.3 | 0.6 | 0.9 | 1.2 | No reticle with filter |
|---|---|---|---|---|---|---|---|
| BC | 0.792 | 0.810 | 0.947 | 0.782 | 0.924 | 1.109 | 0.827 |
| PC | 0.539 | 0.554 | 0.506 | 0.676 | 0.432 | 0.563 | 0.596 |
| RJC | 0.787 | 0.886 | 0.797 | 0.828 | 0.824 | 0.904 | 0.806 |
| | 0.706 | 0.750 | 0.750 | 0.762 | 0.727 | 0.859 | 0.743 |
| Case # | 1 | 2 | 3 | 4 | 5 | 6 | 7 |

Significance of difference from Case # 1

| | # 2 | # 3 | # 4 | # 5 | # 6 | # 7 |
|---|---|---|---|---|---|---|
| P | 0.88 | 0.20 | 0.60 | 0.52 | <.01 | 0.83 |

We observe that there is an increase in resolution threshold resulting from reduction of the overall retinal illumination by filters which is of approximately the size of the difference predicted on the basis of the earlier data in which the brightness of the "twin stars" only was reduced, background brightness being constant. There is a further increase in the resolution threshold, however, as a function of the diameter of the central stop. The effect is significant in the case of the 1.2 mm. stop only. Observer BC, the observer employed in the monocular measurements, exhibits most of the effect. The loss in resolution is approximately the same for binocular and monocular viewing in her case.

Separate measurements were made of the refractive change produced by the central stops by reason of spherical aberration and of the refractive change combined with the accommodative adjustment made by the subject to compensate the refractive change. As before, the stigmatoscope was employed. In order to measure the refractive change alone, rays from the stigmatoscope were intercepted by a reticle prior to entering the right eye of the subject. The refractive condition of the eye was thus determined with a central stop without the subject being able to compensate by accomodation. The averages of thirty settings are presented in Table V.

Table V: Refractive Changes due to Central Stops
(Diopters)

| Observer | No reticle | Central Stop (millimeters) 0 | 0.3 | 0.6 | 0.9 | 1.2 |
|---|---|---|---|---|---|---|
| BC | -0.42 | -0.23 | -0.14 | -0.32 | -0.08 | -0.17 |
| PC | -0.28 | -0.25 | -0.30 | -0.30 | -0.34 | -0.21 |
| RJC | -0.27 | -0.61 | -0.73 | -0.75 | -0.64 | -0.86 |
| | -0.32 | -0.36 | -0.39 | -0.46 | -0.35 | -0.41 |

Observers BC and RJC each demonstrate a systematic change in refractive error when central stops are introduced, which increases as the diameter of the central stop increases. The changes are opposite in direction which presumably indicates that opposite kinds of spherical aberration are present. Observer PC does not exhibit

a change in refractive condition.

Measurements of refractive condition were also made in which the possible accommodative compensation for the refractive change due to the introduction of central stops was permitted. The measurements were made with the subject viewing the fixation points and general background through the reticles. The beam from the stigmatoscope also passed through the reticles. Thus, differences between these measurements and the measurements presented in Table V would be the result of accommodative compensation for the refractive changes produced by introduction of the central stops. Averages of 30 settings are present in Table VI.

Table VI: Accommodative Errors
(Diopters)

| | | Central Stop (millimeters) | | | | |
|---|---|---|---|---|---|---|
| Observer | No reticle | 0 | 0.3 | 0.6 | 0.9 | 1.2 |
| BC | -0.42 | -0.52 | -0.37 | -0.46 | -0.51 | -0.49 |
| PC | -0.28 | -0.22 | -0.34 | -0.35 | -0.31 | -0.23 |
| RJC | -0.27 | -0.40 | -0.25 | -0.44 | -0.44 | -0.25 |
| | -0.32 | -0.38 | -0.32 | -0.42 | -0.39 | -0.33 |

By comparison, it is clear that an accommodative adjustment did occur which appears to have completely compensated the refractive change which BC and RJC exhibited as a consequence of introduction of the central stops.

The binocular data reveal the presence of a change in resolution threshold as the result of the introduction of central stops only in the case of a 1.2 mm. stop. As we have seen, the effect due to overall reduction in retinal illumination of an amount equal to the most extreme such effect of central stops is small and not significant. Furthermore, it was shown that although significant refractive changes occur when central stops are introduced, the subject compensates by adjusting accommodation. Thus, the effect seems to be due to impairment of the quality of the optical image due to diffraction effects. The prediction that the effect of central stops would be greater for binocular than monocular vision was not realized. In these experiments, the subjects exhibited adequate accommodative adjustments to refractive changes due to spherical aberration so that this result is to be expected.

## V. Parallel Bars: Binocular data

When the results of the binocular measurements with the "twin stars" were communicated to Dr. Dunham recently, he expressed interest in the results which would be obtained with the more conventional parallel-bar type test object. Accordingly, preliminary data were obtained for two of the subjects employed in the binocular measurements with the "twin stars."

It is not possible to emply a "forced choice" psychophysical method with parallel-bar targets. If one attempts such a method by requiring the subject to indicate the orientation of the parallel-bars, the subject may obtain the correct answer without discriminating the orientation of the bars by observing the overall shape of the test pattern which varies with test object orientation. Similarly, if the subject is required to discriminate the difference between a parallel-bar test object and a uniform patch of matched average brightness, the subject may respond correctly on the basis of a shape difference between the entire test configurations. For this reason, experiments with parallel-bar test objects must be conducted by simply asking the subject to report "Yes" when he sees the parallel bars. Interpretation of

the results is aided by the use of randomly interjected "blanks," trails in which a patch of matched brightness but without lines is presented.

Accordingly, pairs of parallel-bar and matching blank patches were prepared which were squares 10 minutes on a side. The subject was presented a square uniformly bright patch 40 minutes on a side at all times except when stimuli were presented, in order to maintain adaptation and to provide a constant fixation stimulus. At 6 second intervals, either the parallel-bar or the matching blank patch were presented and the larger square was simultaneously removed. The results obtained are proportions of "Yes" responses for parallel-bar test objects and matching patches.

Our subjects, trained in the use of the "forced choice" technique, experienced considerable dissatisfaction with what they regarded as the arbitrariness of the method. They also quite frequently reported "Yes" on the blank patches. The data were analyzed by allowing for spurious "Yes" responses on the blank patches in the same manner as chance success are treated. This analysis method is of uncertain validity. The data exhibited a degree of day-to-day variability which has never been encountered with these subjects in their use of the "forced choice" technique. Thresholds are based upon visual fits of the data, since the usual mathematical analysis is somewhat meaningless when the data exhibit statistical heterogeneity. The results are presented in Table VII.

Table VII: Binocular Resolution of Parallel Bars
(Minutes of arc)

| | | Central Stop (millimeter) | | | | | |
|---|---|---|---|---|---|---|---|
| Observer | No reticle | 0 | 0.3 | 0.6 | 0.9 | 1.2 | No reticle with filter |
| PC | 0.66 | 0.70 | 0.79 | 0.78 | 0.80 | 0.83 | 0.71 |
| RJC | 0.86 | 0.94 | 0.84 | 0.90 | 0.85 | 0.87 | 0.82 |
| | 0.76 | 0.82 | 0.82 | 0.83 | 0.82 | 0.85 | 0.76 |

It is not possible to test the significance of the differences in threshold, but it seems apparent that the differences are not greater than with the "twin star" targets. The apparent absence of any effect is due to omission of subject BC. In the measurements made with "twin stars" these two subjects exhibited approximately the same degree of effect as is here evident.

## VI. Conclusions

The major conclusion to be drawn from the preliminary measurements is that central stops up to and including 1.2 mm. in diameter do not apparently produce very large differences in resolution threshold under the various conditions tested. For two subjects, for "twin star" and parallel-bar targets observed with binocular vision, there appears to be no more effect than would be expected on the basis of reduction in overall retinal illumination. The third subject exhibits a significant loss in resolution which cannot be explained on the basis of loss in retinal resolution or refractive change due to spherical aberration. It is to be noted that all three subjects apparently compensated completely by accommodative adjustment for changes in refraction produced by spherical aberration.

# DEMONSTRATION OF A HIGH-POWER GREGORIAN TELESCOPE OF REFLECTION OPTICS DESIGN

Lt. Col. Alan E. Gee

At the June 23, 1950, meeting of the Subcommittee on Reflection Optics at New York City, the desire was expressed to construct and test a larger model of one of the Bouwers' Systems. Dr. Hopkins undertook the optical design of this instrument, and I undertook the mechanical design and construction. The optical elements for the instrument were produced by Mr. Klinkert of the Optical Shop of the University of Rochester.

Plate No. 1 shows the scaled optical layout of this instrument. The over-all length between the two elements of the objective is 12-1/2 inches and the aperture at the meniscus is 3-3/8 inches. The diaphragms are not indicated on this optical layout. However, it is apparent that without diaphragming, light that has passed through the meniscus, but has not suffered the two reflections from the objective system, could fall directly on the focal plane and fog the image. The two diaphragms provided to prevent this will be discussed in a moment. It will be noted from this diagram that the Gregorian secondary mirror is operating at a high nagnification, this being approximately 7X. As a result of its small size and high magnification, this little mirror surface is extremely critical as to precise positioning both longitudinally and laterally. The effective focal length of the objective system used in this instrument is approximately 70 inches, yet its overall length is only 16 inches. The magnification of the instrument is 65X. The prime advantage lies in the fact that this high nagnification can be achieved in a very short, light and compact instrument, yet still utilizing a low powered eye piece of long and comfortable eye relief.

Plate No. 2 illustrates the general details of the mechanical construction. The two diaphragms used to prevent direct sky light from reaching the focal plane are indicated. One of these diaphragms located at the meniscus end of the instrument is supported by a spider. The lower diaphragm at the eye piece end of the instrument is mechanically mounted to the hold in the primary mirror itself. It is of interest to note that the upper diaphragm, which necessitates the use of a spider with resulting diffraction effects, is absolutely essential to the Gregorian system to prevent sky fogging. This is not the case if the Cassegrainian form is used. In this latter case, the upper diaphragm may be eliminated, and subsequently, the necessity for the spider. The Cassegrainian form, also, is appreciably shorter than the Gregorian; however, it suffers the serious disadvantage of having an inverted image. The mechanical construction of this instrument is quite conventional, except that clearances in the meniscus and mirror cells have been held very close for accurate lateral positioning of the elements. The instrument is constructed of 24ST aluminum alloy throughout. The optical elements are anti-reflection coated, and the aluminized surfaces are protected by a 1/2 wave layer of magnesium fluoride.

Only a very short period of time was available in which to construct this instrument, and it was finally assembled for the first time only two days before this meeting. Consequently, tests of the instrument have been extremely limited in nature. The magnification of the instrument is 65X. Its effective aperture is 86mm. Apparent field is 45°, and eye relief is 3/4 inch. The limiting resolution on a Foucault bar target is 1.5 seconds of arc. This compares with the Rayleigh limit for that aperture of 1.25 seconds. Vignetting at the edge of the field is approximately 50%. This is not sufficient to be objectionable in normal visual use. A noticeable characteristic of the instrument is its complete lack of detectable secondary spectrum. Images are completely free from the color fringes so common in conventional refractors. Time

did not permit making contrast rendition measurements of the instrument nor measurements of transmission.

Construction of this instrument has disclosed several difficulties inherent in this type of design. One has been mentioned above; namely, the extreme sensitivity of the secondary mirror, and consequently, the entire meniscus to position. Not only must the cells be held to very close tolerances, but provision must be made for longitudinal adjustment of the meniscus element. The meniscus itself is very thin for its diameter; consequently, very subject to flexure in mounting. The transmission portions of this element are not particularly sensitive to flexure; however, the aluminized spot in the center of the element acting as the Gregorian secondary is extremely sensitive. With the secondary mirror operating at a magnification of approximately 7X, the movement of the image in the focal plane of the eye piece for a corresponding longitudinal movement of the secondary, is approximately 50 to 1. From this it is apparent that the movement of the eye piece necessary to focus an instrument of this type having its long conjugate appreciably shorter than infinity must be very long. In point of fact, the eye piece must move to infinity for even a comparatively distant object. The eye piece movement utilized on the present instrument (1/4 inch) is only sufficient to focus the instrument from infinity to 450 yards. The only reasonable solution to correct this difficulty is to vary the longitudinal spacing of the two mirrors in focussing. This presents appreciable construction difficulties due to the comparatively large diameters of the elements involved. It follows logically that large longitudinal image movement will be encountered in this instrument with shrinkage or expansion of the main tube with temperature changes. Further, due to the close tolerance necessary for positioning the optics, the instrument could not be expected to maintain intact the cold temperatures for which military equipment must be designed. In any mass production of an instrument of this type, the meniscus lens would provide a serious production problem. This element, representing a 60° portion of a sphere, is practically a concentric lens. Consequently, it must be centered in grinding during manufacture and cannot be edged for accurate centering after polishing as with conventional elements.

It is my conclusion that this type of instrument presents advantages in overall size and weight for a high powered instrument, but that other disadvantages render it unsuitable for general military application.

Optical Diagram - Gregorian Meniscus Telescope

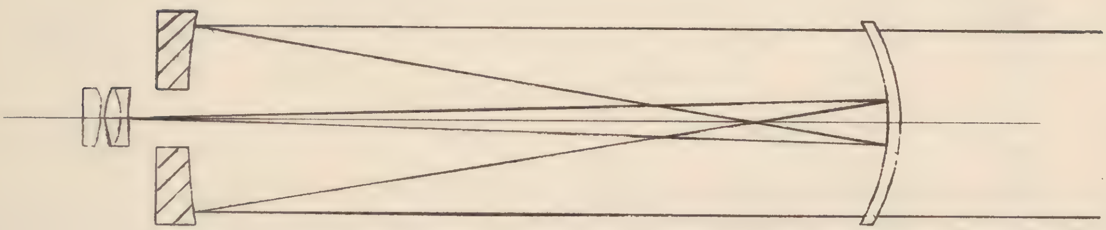

Plate 1

68 · 86 MENISCUS CORRECTED GREGORIAN TELESCOPE

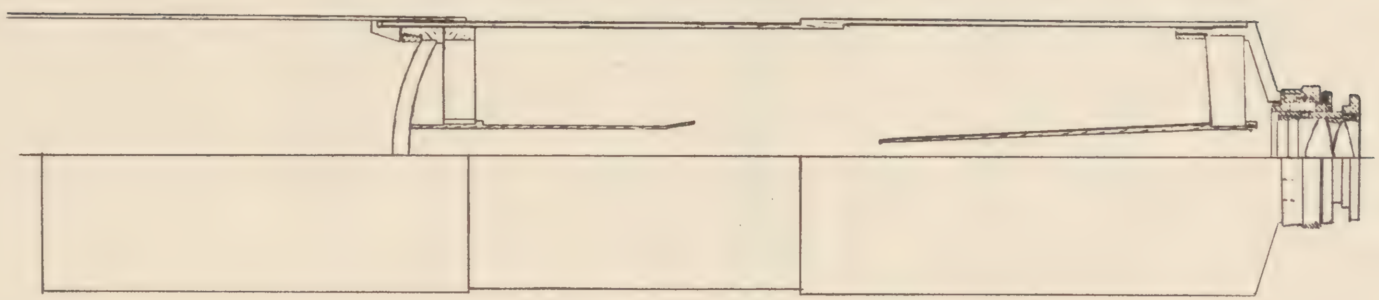

Plate 2

Discussion of the reports on reflection optics

Dr. Fry asked whether there was not a fundamental difference in the results obtained by Dr. Blackwell and Dr. Tousey in their studies of the effect of central stops upon visual resolution.

Dr. Blackwell reported that he did not believe there was any fundamental discrepancy between the two reports. Dr. Blackwell pointed out that one of his three subjects showed most of the effect, but that there was a significant loss in resolution with "twin stars" when the central stop became as large as 1.2 mm. for all subjects combined. The losses in resolution reported by Dr. Tousey were for central stops as large or larger than 1.2 mm. Dr. Blackwell agreed that the two subjects tested with parallel bars did not show an effect, but pointed out that these subjects were the ones which showed very little, if any, effect in the "twin stars" experiment. Dr. Blackwell concluded that there were individual differences in the results. He concluded also that both his results and those of Dr. Tousey agreed in showing that there was very little if any effect with central stops smaller than 1.2 mm., and that, generally speaking, there was an effect at 1.2 mm. and above.

Dr. Hulburt asked whether it was not true that the losses in resolution all were found to occur with central stops larger than would almost ever be used in reflection optics design.

Dr. Dunham agreed that this was the case.

Dr. Kincaid asked whether Dr. Dunham had studied the diffraction patterns for white light as well as for monochromatic light. He pointed out that if you construct the diffraction pattern for white light from patterns obtained with monochromatic light employing luminosity weightings, the patterns change in important respects.

Dr. Dunham stated that he had not investigated white light from the standpoint of visual luminosity, but that, of course, there would be changes in the form of the diffraction patterns.

Executive Council Meeting
Tuesday, November 9

Colonel Byrnes reported briefly upon the activities of the Executive Council in its meeting on November 9. He stated that items of budget and procedure were discussed in some detail. The bulk of time in the Executive Council meeting was devoted to considering the need for activities by the Vision Committee in certain special areas of visual problems. Colonel Byrnes outlined some of the areas which the Executive Council believed the Vision Committee should begin to study as follows:

The Air Force requested that the problem of visibility at high altitudes be taken under study by the Vision Committee. Colonel Byrnes noted that a preliminary discussion of the problem was presented by Dr. Blackwell on Friday and stated that the Vision Committee will continue to study this problem for the Air Force. A second aspect of this problem which has recently come to the attention of the Executive Council concerns the characteristics of visibility in the arctic twilight. It is desired that information be given as to conditions under which flight may be undetected from the ground at some times and detected at others, depending upon the conditions of lighting and sky brightness.

The Executive Council also considered that there was a need to study possible new optical aids to vision. This work would logically be a kind of extension of the work of the present group on reflection optics.

Another proposal made to the Executive Council was that the work already done on the characteristics of illumination for adequate protection of dark adaption be summarized in such a way that standards could be proposed in some cases.

The general characteristics of the problem of viewing of radar which will lead to optimal visual performance is considered to be of great interest to the military departments. All the services employ radar equipment, and in many instances the operators of this equipment are required to use it for prolonged periods of viewing. The conditions under which radar is viewed are considered to be by no means adequate at the present time.

At the request of the Aero Medical Laboratory, a working group is to be set up to consider problems of airplane cockpit illumination. This again is a subject many parts of which are completed, but the entire material has not been collated so that unambiguous recommendations can be made.

The Army has requested that information be made available to them concerning the utilization of sunglasses in the arctic region. In this case, insufficient information has been received from the Army for the Vision Committee to undertake activity, but it is expected that further information will soon be obtained.

Colonel Byrnes stated that Captain Shilling wished to make a brief statement about a further problem which was discussed by the Executive Council.

Captain Shilling commented on the desperate need in the services for scientific assistance, both in research laboratories and research conducted under service contracts. Captain Shilling stated that in talking with various universities, he has found them more than willing to cooperate in any way necessary to facilitate in research for use of the services. He stated that a number of universities have offered to make whole departments available for military use. Captain Shilling stated his belief that it would not be necessary for the services to take over entire

departments at the present time.

Captain Shilling asked members of the Vision Committee to think about the problems in vision of particular importance to the military and to be sure to contact military departments to inform them of any conclusion reached as to the nature of these problems and possible research solutions. Such contacting of the military departments could be handled either through the Vision Committee, or directly. Captain Shilling also emphasized the need to encourage graduate students to conduct research projects which would further the work of the military departments. Arrangements can be made whereby graduate students can do thesis research in Government laboratories or the students can carry out the research in university laboratories in some cases. Captain Shilling expressed the opinion that the universities might wish to consider having each graduate student work on two problems, one of a theoretical nature, and one of a practical kind for the doctral dissertation.

In summary, Captain Shilling appealed to the group to appreciate the significance of the scientific manpower problem which is facing the military services, and to do whatever they can to improve the situation.

ABSTRACTS

278. Vertigo Incidence Among Naval Aviators
Howard E. Page
U.S. Naval School of Aviation Medicine, Naval Air Station, Pensacola, Florida, Joint Project Report No. 16, The Tulane University of Louisiana under Contract N7onr-434 T.O.I. Office of Naval Research, Project Designation No. NR 140-455 and the Bureau of Medicine and Surgery Project No. NM 001 063.01.16 (formerly NM 001 037) 15 pp. March 1950 (O)

"One hundred and ninety-four Naval Pilots were asked to complete a questionnaire in which they were to consider 54 verbatim reports of vertigo experienced by other pilots. They were instructed to consider each item, indicating 1) if they had experienced the same or similar situation, 2) if they felt the experience was common among pilots, and 3) if they considered it important and serious to aviators. In addition, they provided information about their personal experiences, wrote a description of the most vivid vertigo instance experienced by them, and answered a series of true-false items pertaining to their personal characteristics.

"Data relative to the incidence of vertigo among naval aviators are presented in this report. Other data will be presented in subsequent reports.

"The following conclusions may be drawn:

"1. The mean frequency of vertigo items reported as 'experienced' by pilots was 10.97. This incidence of vertigo is greater than that considered in the 'much vertigo' group reported by Vinacke.

"2. The mean frequency of vertigo items reported as 'common' was greater than for items 'experienced' and an even greater incidence was reported as "important" to pilots.

"3. The greater the experience, the greater the incidence of vertigo experiences reported by pilots. Differences found, however, were not generally statistically significant.

"4. No significant differences were found in incidences reported by multi-engine and single engine pilots.

"5. Vertigo incidents classified as 'Non visual' were reported as 'experienced' most frequently, followed by 'Conflicting Sensory,' 'Visual,' 'Dissociational or Recognitional,' 'Emotional' and 'Fascination' in that order."

279. Design of Visual Testing Device
J. Vaccaro, Jr.
US Naval Base, Philadelphia. Report No. NAES-* Instr. 86-49. 3 April 1950 6 pp. (O)

"A device has been built to facilitate study of performance on instrument dials under various lighting methods and techniques. The device consists of four standard aircraft instrument dials mounted in a circular pattern on a test panel. The panel is covered by a shutter so that only one instrument is exposed at any time. The shutter is driven by a constant speed motor through 90° everytime the subject actuates a switch. Each of the four instruments is constructed so that one of twenty predetermined readings is indicated on its dial when exposed by the shutter. The dial

setting of the exposed instrument changes as the shutter moves from one to the next position. In this way, it is possible to present eighty predetermined dial readings, twenty on each instrument."

280. Design of Instrument Dials for Maximum Legibility
Part 3. Some Data on the Difficulty of Quantitative Reading in Different Parts of a Dial.
William E. Kappauf and William A. Smith
United States Air Force, Air Command, Wright-Patterson Air Force Base, Dayton, Ohio
AF Technical Report No. 5914, 14 pp. May 1950 (O)

"This is the report of an analysis to determine whether the likelihood of error in quantitative reading is greater in one part of a dial than in another. The error data which are examined are based on over 45,000 dial readings made in the course of two experiments involving a total of 28 subjects.

"No evidence is found which would indicate that local scale reading errors (errors of rounding interpolation, and the like) vary with dials sector. The frequency of systematic scale reading errors depended on dial sector for dials graduated from 0 to 50 or from 0 to 100 but not for dials with scale ranges of 0 to 200, 0 to 400, or 0 to 600. The 50's and 100's dials were similar in that they were numbered by ten unit steps. The dominant error made in reading them was an error of reporting a scale value too great by ten units. This error was more prevalent on the right dial halves than on the left and was especially frequent in the scale region from 0 to 9.

"Thus, while sector has no consistent effect on either local errors or systematic errors for many dials, it may influence the occurrence of specific systematic errors on certain scales. As more is learned regarding scale design factors related to systematic errors, the easier it will be to account for the effect of sector on the ten units error here reported or to identify other dial designs which may produce error patterns varying with sector."

281. The Relation of Mounting Angle of Display to Fatigue In The Observer
D.C. Fraser
Great Britain - Medical Research Council. Applied Psychology Research Unit. The Psychological Laboratory, Cambridge
APU 108/49 July 1949 (R)

"An experiment is described to test the relation between angle of display and performance in prolonged visual tasks, using the Clock Test in three positions of display surface, vertical at an angle of 45° to the horizontal, and horizontal. In every case the line of regard was kept at right-angles to the display surface.

"The results indicate: -

(i) That significantly fewer stimuli are missed in the vertical position of the display than in the other two.

(ii) That the Clock Test can be used in a different setting from the original experiment with reasonably consistent results.

(iii) That the observer may be reacting to a relationship between the single and double stimuli rather than to the physical magnitude of the stimulus.

(iv) That the subject's own display preference often has little relation to his actual performance."

282. <u>Design of Instrument Dials for Maximum Legibility. Part 4.</u>
Dial Graduation, Scale Range and Dial Size as Factors affecting the Speed and Accuracy of Scale Reading
William E. Kappauf and William M. Smith
U.S. Air Force, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio. AF Technical Report No. 5914
February 1950 (C)

"This study was conducted for the purpose of gathering quantitative evidence on the extent to which dial reading errors and reading times are influenced by the spacing of graduation marks, graduation mark values, scale range, and dial size.

"The dials employed were scaled from 0 to 50, 0 to 100, 0 to 200, 0 to 400, and 0 to 600 units. Graduation schemes included graduations by tens, fives, twos, and units. Dial sizes were 2.8 inches and 1.4 inches. Twenty subjects read these dial materials on cards of 12 dials each under instructions to read to the nearest unit and to work as rapidly as possible. In all, 34,400 readings were involved.

"The results show that the precision of scale reading, as measured by the frequency of errors of interpolation, rounding and the like, varies with the distance on the scale allocated to each scale unit. Reading precision improves as the distance increases to about 0.05 inches, a value which varies only slightly with graduation scheme but which appears to vary with graduation mark thickness. For more expanded scales, reading precision remains reasonably uniform at a level which depends on graduation scheme. Here, graduation, by units or twos is better than graduation by fives, which in turn is better than graduation by tens.

"Systematic or large scale reading errors seem to be determined by the same factors or conditions which determine reading time, namely, scale range and those aspects of graduation mark organization which must vary when longer and longer scale ranges are accommodated on a dial of a given size.

"Although this abstract tends to focus attention on the direction of observed differences in error rates and reading times between dials of different design, the primary purpose of the report itself is to show the approximate magnitude of these differences. Such measured differences represent an essential part of the information needed by an engineer when weighing the advantages and disadvantages of alternative scale designs for particular instruments."

283. A Study of Requirements for Color, Size and Shapes of Aircraft Instrument Dial Markings. Part 1 - Type and Format for Sight Reduction Tables. TED NO. NAM EL-618
Fred R. Brown
U.S. Naval Air Materiel Center, Naval Air Experimental Station
Aero Medical Equipment Laboratory, Philadelphia, Penna.
12 July 1950. Report XG-T-139. 11 pages (0)

"From a critical review of the current literature and application of psychological and visual data, opinions and conclusions were drawn regarding type and format for use in Sight Reduction Tables. Application of the information will make for greater legibility of the tables and aid in the ease, speed and accuracy of extracting the data, especially when used with low-level red illumination."

284. Direction of Pointer Motion in Relation to Movement of Flight Controls. Cross-Pointer Type Instrument AF Technical Report No. 6016.
John F. Gardner, 1st Lt, USAF
United States Air Force, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio. June 1950
20 pp. (0)

"To determine the optimal relationship between pointer movement and control movement for such instruments as the ILAS cross-pointer and the Zero Reader, 48 pre-flight cadets were tested on a two-dimensional pursuit task in a closed cockpit with a cross-pointer type instrument display. Four combinations of movement relationships were investigated. Results showed that the movement relationship involving the vertical pointer is dominant, that a 'direct' for 'fly from' relationship between the movement of this pointer and the movement of the control produced significantly superior performance, and that most subjects preferred this relationship. It was further shown that, although performance reflected an unannounced reversal in the movement relationships of both pointers, a third of the subjects were completely unaware of the reversal and another third were aware of reversal of the vertical pointer only. Further research is necessary to determine the facility with which practice on 'fly from' indicators will improve the performance of experienced pilots who have had more or less extended practice with existing instruments."

285. <u>The Effect of Illumination on Dial Reading. AF Technical Report No. 6021</u>
E. Laurence Chalmers
Mymon Goldstein
William E. Kappauf
United States Air Force, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio. August 1950
25 pp. (0)

"Eight subjects participated in this experiment to obtain some new date on the effect of lowered illumination on the speed and accuracy of dial reading. Dials of 12 types and two sizes were used.

"Interpolation and other local errors are found, for hard-to-read dials, to increase progressively as brightness decreases. Gross errors and reading times, on the other hand, change very little with decreasing brightness until a critical level is reached. This critical level is very similar for all dials with a given size of marking.

"Other data which are described indicate that the critical level for any given dial can be determined from number reading tests or by obtaining judgments of minimum acceptable illumination levels from careful observers."

286. <u>Eye Fixations of Aircraft Pilots. V. Frequency, Duration, and Sequence of Fixations When Flying Selected Maneuvers During Instrument and Visual Flight Conditions.</u> AF Technical Report No. 6018
John L. Milton, 1st Lt, USAF
Richard E. Jones, Capt. USAF
Paul M. Fitts, Ph.D.
United States Air Force, Air Materiel Command Wright-Patterson Air Force Base, Dayton, Ohio. 33 pp.
Aug. 1950 (0)

"This report summarizes data concerning the frequency, duration and sequence of eye fixations made by ten USAF pilots during straight and level flight and standard rate turns performed under simulated instrument conditions, and during take-offs and landings performed under contact conditions.

"Fixations per minute on the flight instruments varied from 4 on the turn and bank indicator to 26 on the directional gyro during straight and level flight, and from two on the vertical speed indicator to 18 on the directional gyro during standard rate turns. During both maneuvers the directional gyro was checked most frequently and the gyro horizon next most frequently. The flight instrument which required the longest fixation time was the directional gyro.

"During take-offs and landings performed under contact conditions, more fixations and much longer fixations were made on reference points outside the aircraft than on any particular instrument. The engine instrument panel was checked much more frequently than was any flight instrument during the take-off. The air speed indicator was checked most frequently during the landing.

"Eye movement link values, based on the frequency of movements in both directions between each instrument and every other instrument, are presented. The pattern of eye movements during standard rate turns and during straight and level flight is relatively complex since no specific pair of instruments accounts for a large proportion of eye movements involved. During take-off this pattern is relatively simple since two instruments and the outside reference account for approximately six-tenths of the eye movements involved. During landing two instruments and the outside reference account for approximately eight-tenths of the eye movements involved.

"From these date an optimum arrangement of instruments on the panel can be determined. Since this arrangement varies for different maneuvers, and since the data are probably somewhat affected by the particular arrangement used in their collection, decisions on this point should not be made considering only the data presented herein."

287. Some Variables Affecting Instrument Check Reading. AF
Technical Report No. 6024.
Shirley C. Connell
United States Air Force, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio 11 pages August 1950 (0)

"As part of extended studies of human factors in aircraft instrument check reading, two studies were conducted in one of which subjects check read panels of simulated instruments, and in the other singly presented numbers ranging in size from two to seven digits. In the first study, panels of four identical simulated indicators, all aligned at the same setting, were checked for significant deviations from the reference setting. This simulated part of the task of pilot or flight engineer in checking the engine instrument panel of a four-engine airplane. Three panels were compared, each embodying a different common principle of indication. Average time and percent of errors of twenty subjects in detecting significant deviations in setting among four circular dials with rotating pointers were approximately half as great as time and errors in detecting deviations among four direct reading counters or indicators with a scale rotating behind a fixed pointer.

"In another separate study, numbers varying only in number of digits (from two to seven digits) appeared in the same exposure apparatus as was used above. Time and errors in detecting differences between verbally and visually presented numbers were recorded for twenty subjects. Speed and accuracy increased directly as the number of digits decreased from seven to two digits, indicating that in counter type indication, there is almost a linear increase in time and a similar increase in errors for each addition of a column beyond two columns."

288. Peripheral Visual Acuity: A Review
Frank N. Low
Dept. of Anatomy, School of Medicine, Johns Hopkins University, Psychophysiology Branch, Human Resources Division, Office of Naval Research, Navy Department, Washington, D. C. 24 pp. June 30, 1950.

"The pertinent literature on peripheral visual acuity is reviewed. A short historical sketch is followed by graphical comparison of the quantitative results of different investigations. Visual acuity falls off from fovea to periphery, rapidly at first and then more slowly if fractionally compared to central vision. It decreases in almost linear fashion, however, if plotted in terms of angular deviation against angle subtended by the test object, or the discriminating portion thereof at

the eye. The numerous factors known to affect peripheral acuity are discussed with reference to the published data. The probable reasons are discussed for the poor agreement among the various investigations. Individual variability appears to be the chief cause with test object differences and brightness of illumination having some effect. The remaining factors are less likely to have been responsible for any discrepancies under the experimental conditions used. The reason for decreasing acuity in the periphery is discussed. The rod and cone populations are concluded to be the most likely single cause, although the rod population correlation is poor, and that for the cone population is based on single cases. Over 100 references are cited."

290. The Effect of Colored Lenses Upon Color Discrimination
Dean Farnsworth, H. (S), USNR
Medical Research Laboratory, U.S. Naval Submarine Base, New London, Color Vision Report No. 9. 15 pp, September 3, 1945 (O)

"Six commercial types of sun glass lenses were used in six laboratory tests to determine their effects on color perception, during and immediately after the wearing. Neutrals (types, Neutral and Polaroid) and greenish-gray lenses (types, Rayban and Calobar) produced little distortion of color perception as measured by any test. Brown lenses (type, Rose Smoke) caused considerable decrement in color discrimination and a yellow lens (type, Noviol) caused extreme decrement. None of the lenses increased color perception in any part of the color range. It is concluded that greenish-gray lenses of the Rayban and Calobar type do not seriously impair color perception when used for the observation of non-dichromatic materials.

"A study was made on the after effects of wearing the lenses; it appears that adaptation proceeds rapidly and is half completed in about 5 seconds. There are appendices on the measurement of spectral transmittance of polarizing film and on methods of specification of neutrality for sunglasses."

291. Diving Experiments. Underwater Vision and Ocular Comfort
C.L.T. McClintock
Medical Research Council. Royal Naval Personnel Research Committee. Office of Naval Research, American Embassy, London England. 9 pp. September 13, 1950. Copy No. 22. (R)

Experiments are here reported on the development of special contact lenses for use in underwater seeing. The special lenses are designed to correct for the difference in refractive index of air and water.

292. A Factorial Analysis of Depth Perception Tests
Lyle H. Lanier and Margaret E. Tresselt
Psychological Research Center, New York University
42 pp. 1950 (O)

"A report is given of the results of factor analysis of the data of 228 men who were given a collection of tests which were presumed to be related to depth perception. The tests were as follows:

1. Howard-Dolman binocular depth perception test (at 20 feet)
2. Howard-Dolman adaptation for monocular motion parallax
3. Sight-Screener -- far stereopsis (Sloan's circles)
4. Sight-Screener -- far acuity (Sloan's Landolt rings - both eyes)
5. Sight-Screener -- near stereopsis (Sloan's circles)

6. Sight-Screener -- near acuity (Sloan's Landolt rings - both eyes)
7. AAF Distance Estimation Test CP212-A (Gibson, size-at-a-distance)
8. Ortho-Rater F-6 -- far stereopsis
9. Ortho-Rater F-5 -- checkerboard: far acuity, left eye
10. Ortho-Rater F-4 -- checkerboard: far acuity, right eye
11. Ortho-Rater F-3 -- checkerboard: far acuity, both eyes
12. Ortho-Rater N-3 -- checkerboard: near acuity, left eye
13. Ortho-Rater N-2 -- checkerboard: near acuity, right eye
14. Ortho-Rater N-1 -- checkerboard: near acuity, both eyes
15. Ortho-Rater F-1 -- far vertical phoria
16. Ortho-Rater F-2 -- far lateral phoria
17. Ortho-Rater F-7 -- color
18. Ortho-Rater N-4 -- near vertical phoria
19. Ortho-Rater N-5 -- near lateral phoria
20. Telebinocular circles: near acuity, both eyes
21. Telebinocular signposts: far acuity, right eye
22. Telebinocular signposts: far acuity, left eye
23. Telebinocular near stereopsis
24. Telebinocular far stereopsis
25. Howard-Dolman-Weinstein (tilted, colored targets at 10 feet)
26. Ames-Tresselt size-depth adjustment
27. Ames-Bakan interposition illusion
28. Verhoeff Stereopter

The principal factor extracted has been designated "Stereopsis" and the secondary factor extracted has been designated 'Retinal resolution.' Other factors of less significance are extracted as well.

"Factor I. Stereospsis. All of the eight binocular tests have significant and substantial loadings on this factor; some 25 to 62 per cent of their score variance is accounted for by Factor I. There are no consistent differences in size of factor loading between the 'simulated' and the 'real' depth variables. Only one of the monocular depth tests, however, has a significant coefficient for Factor I and it accounts for only about 10 percent of the score variance (monocular motion parallax). All of the visual acuity tests have significant, but mostly low, loadings on Factor I (the percentage of score variance accounted for ranges from 5 to 20). As for the phoria tests, Factor I has no significant loading for the first matrix, but the retest results show significant loadings for the two vertical phoria tests.

"Factor II. Retinal Resolution. All of the visual acuity tests have significant loadings on this factor. The highest coefficient is found for Ortho-Rater far acuity (retest), where some 50 per cent of the variance of scores is accounted for by Factor II. The eight binocular depth variables have mostly low and barely significant loadings on 'Retinal Resolution.' And none of the other variables has significant and consistent loadings on this factor, except near lateral phoria. In this case, Factor II accounts for 4.3 and 6.6 per cent of the variance (test and retest).

"General Conclusions

"a. The results of the present study fail to support the view that 'depth perception' is a homogenous behavior category. Judgments of depth and distance based upon different cues or secured in dissimilar situations tend to show only slight interrelationships.

"b. Even among tests based primarily upon binocular disparity (stereo acuity), a high degree of non-relationship among scores is found. The factor called

'Stereopsis' accounts at most for about 62 per cent of the score variance and on certain of the binocular depth tests the percentage drops as low as 20.

"c. Comparisons of "real" depth tests with the 'stereoscopic' machine tests fail to show any systematic differences. On the whole the factor loadings on Factor I (Stereopsis) are similar in range and magnitude for the two groups of tests. Moreover, the original intercorrelations are about as high between tests of the two groups as among tests within each category. But again the fact that individual tests are not interchangeable should be stressed; for both groups of tests specific and error variance is fairly high.

"d. The monocular tests were all virtually unrelated either among themselves or to other variables included in the study. The lack of communality meant that the factorial composition for these tests could not be determined. Successful and definitive factor analysis in this field must be preceded by extensive experimental research and test development designed to yeild a set of several reliable variables for each of the important monocular cues.

"e. It is suggested that future investigation might profitably follow either or both of two courses: (1) systematic experimental analysis of the manner in which the several types of visual cues influence judgments of depth and distance, followed by the development of "clusters" of reliable tests based upon each stimulus variable; (2) the direction of experimentation and test development towards the analysis of the visual requirements of a particular type of job. The former approach would establish the basis for a comprehensive factorial analysis of depth perception and related functions. The second approach would yield a more restricted analysis of the organization of visual functions but might provide a set of instruments appropriately weighted with reference to the assessment of visual qualifications for the specific occupational area."

292. Perceptual Anticipation in Tracking
E.C. Poulton
Medical Research Council, The Psychological Laboratory, Cambridge
A.P.U. 118/50, 23 pp., August, 1950. (0)

"In order to discover the part played by perceptual anticipation in tracking under different conditions, two experimental arrangements were used. In one the subject had to trace regular or irregular courses under conditions of restricted vision, with or without a preview. In the other the subject either had to keep a pointer in line with a second pointer moving in a harmonic course, using a positional control; or had to keep a single pointer, moving in this way, stationary on a fixed line.

"It was concluded that perceptual anticipation is a normal component of adult human tracking performance. It can take two forms: speed anticipation, in which the subject's decision is based upon his perception of, or inference about the speed of the 'stimulus' movement at the time; and course anticipation, in which it is based upon his general idea of the 'stimulus' course.

"The term 'tracking' includes two very different tasks, two pointer matching and one pointer matching and one pointer balancing. The extra information afforded by the two-pointer display enables the subject to anticipate consistently. The two pointer matching was thus found to be about twice as accurate as one pointer balancing.

"A detailed study of the subject's two pointer matching performance with a high speed

simple harmonic cam, led to the conclusion that he was performing a complex dual task.

"When tracking conditions are such that the subject cannot only anticipate the future 'stimulus' course, but can actually control it, anticipation can assume a new and more active role. Experimental results suggest that this is a practical possibility, which might be used to increase the accuracy of certain tracking tasks."

293. Speed Anticipation and Course Anticipation in Tracking
E.C. Poulton
Medical Research Council, Applied Psychology Research Unit, The Psychological Laboratory, Cambridge, A.P.U. 123/50, 12 pp., September, 1950 (0)

"In order to study separately the two kinds of perceptual anticipation in tracking speed anticipation and course anticipation, two different experimental arrangements were used. In one the subject had to predict the position of a pointer moving in harmonic motion, at a given time ahead. In the other the subject had to keep a pointer in line with a second pointer moving in harmonic motion, when he only received intermittent glimpses of the display.

"It was found that it was not the length of time ahead, but what happened during that time, which determined the accuracy of perceptual anticipation at different distances in the future.

"The importance of speed anticipation in 'blackout' tracking was demonstrated experimentally by reducing the length of the glimpses of the display, so that the subject could see only the successive positions of the 'stimulus' pointer at fixed intervals of time, not its speed in these positions. His performance deteriorated accordingly."

294. An Investigation of Certain Aftereffects of Intermittent Radial Acceleration
N.D. Warren
Psychological Research on the Human Centrifuge, Report Number 8. The Psychological Laboratory, The University of Southern California, 19 pp, October, 1950. (0)

"1. Healthy young male students were employed as subjects in an attempt to determine the aftereffects of prolonged exposure to moderate g intensities.

"2. The subjects were divided into experimental and control groups. A battery of six tests was administered to each group before rotation on the human centrifuge and again at the conclusion of the rotation.

"3. The experimental group was subjected to 3 g's for one minute every eight minutes for a total of 7 minutes. The same exposure schedule was employed for the control group except that the g intensity was 1-1/2 g instead of 3 g. (Note: a body at rest on the surface of the earth is being accelerated toward its center with a force of one gravity.)

"4. An analysis of the results was made. T-ratios of the mean differences were computed in order to evaluate the within group differences, and t- ratios based on the mean gains were computed for the between group differences.

"5. The following general conclusion was reached:

a. In the main, the abilities tested were unaffected by the prolonged exposure to g, with the following exceptions:

(1) the improvement of the experimental group was significantly less than the improvement of the control group in the time required to name colors (significant at the 1% level); and

(2) the improvement of the experimental group was significantly less than the improvement of the control group in the number of contracts made in the Steadiness Test (significant at the 5% level)."

295. Report On Night Vision
William John Holmes, M.D.
U.S. Navy. Office of Naval Research. Project No. NR 141-005
Contract N9onr-97600. 13 pp mimeographed. (0)

William John Holmes, M.D. of Honolulu, Hawaii here reports progress in his investigations of night vision tests. Dr. Holmes reports conferences in the U.S. and abroad. He then outlines the kinds of night visual examinations which might be employed in the armed forces services. These he classifies as: screening tests, quantitative tests, special tests, and objective tests. Dr. Holmes then described a proposed screening test, a proposed quantitative test and a proposed objective test which he is in the process of developing.